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PREDICTION OF NON-POINT POLLUTION OF STREAMS AND RIVERS.(U)

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6 PREDICTION OF NON-POINT
POLLUTION OF STREAMS AND RIVERS

9 Master's thesis,

by

10 John E. Hesson

An essay submitted to The Johns Hopkins University
in conformity with the requirements for the degree
of Master of Science in Engineering

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ABSTRACT

This study investigates the utility of a nonpoint pollution model and its various included terms as predictors of average annual nonpoint stream loads of sediment nitrogen and phosphorus. The model as a whole was found to be of marginal value but the basin area term was found to have high correlation to total nonpoint pollutant loads. The logarithms of the unit area loads of soluble nitrogen and phosphorus were found to be normally distributed allowing means, standard deviations and probabilities to be calculated.

ACKNOWLEDGEMENTS

I would here like to acknowledge and express my appreciation for the advice and assistance that I have received from my advisor and department chairman, Dr. M. Gordon Wolman. Without his help this study would not have been possible. With his help and encouragement I have produced this essay which I hope will be useful in the continuing investigation of nonpoint pollution.

I have also received assistance in specific areas from Dr. John G. Cady and from Dr. Jerome Gavis who are also with the Department of Geography and Environmental Engineering at The Johns Hopkins University.

Most of all I want to thank my wife Nancy for her support and seemingly endless patience through the entire period of my studies at Johns Hopkins.

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I. PURPOSE OF THE STUDY

The purpose of this study was to investigate the prediction of non-point agricultural pollution of streams in the middle and eastern United States. Equations proposed by the Midwest Research Institute in a 1975 draft report were tested by comparing their predicted sediment and total nutrient loads with measured sediment, and total and soluble nutrient loads in twenty-three streams from New York to North Carolina and from New Jersey to Iowa. The objective of this study was to be able to predict for any given stream the amount of non-point agricultural pollution on an annual basis.

II. INTRODUCTION

Until relatively recently water pollution has been dealt with almost exclusively as an urban and industrial effluent problem and had little, if any, concern with stream pollution arising from natural, overland runoff, or non-point sources. Decision makers will undoubtedly be called upon to take continuing steps to reduce the levels of pollution in streams and rivers. As abatement and control of point source pollution hopefully becomes more extensive and effective, the relative contribution of non-point sources will increase and perhaps become the limiting factor determining water quality.

In order to make informed decisions one must have some knowledge of the magnitude and nature of non-point pollution. For this reason it is becoming increasingly important to learn more about the processes that govern non-point pollution in order to better predict the amount and characteristics of such pollution and to be able to take the steps necessary to reduce it where acceptable levels are exceeded.

Non-point pollutants can be in the form of sediment, excess plant nutrients, pesticides, toxic chemicals, pathogens and organic matter. This study is limited to an investigation of annual loads of sediment and the two major nutrients, nitrogen and phosphorus.

Excessive sediment is one, if not the, major stream pollutant.

Its presence not only makes water unsuitable for many uses but one or several other pollutants may be transported bound to the particles of the sediment. Excess sediment can fill reservoirs at accelerated rates and require expensive maintenance of channels in navigable waters. Erosion of the sediment may also reduce the value of land as a source of agriculture or natural habitat[1].

Plant nutrients, that is nitrogen and phosphorus, are also major non-point source pollutants. These nutrients when present in excessive amounts can cause accelerated growth of algae in bodies of water[2]. Excessive biomass of algae can cause several water quality problems. Algae may introduce foul tastes and odors in water reducing its usefulness for consumption and recreation. Large amounts of algae can deplete dissolved oxygen and result in "fish kills". In addition, excess nitrogen in the form of nitrate can be a health hazard to man and animals.

The method used here to investigate non-point pollution prediction is the testing of a set of equations adopted and developed by the Midwest Research Institute for use in a study undertaken for the National Commission on Water Quality[3]. These predictive equations were applied to twenty-three watersheds in the central and eastern United States and the results compared with actual pollutant loads measured in the streams. A term by term analysis of impacts on pollutant load was undertaken to determine the relationship of the terms

in the predictive equations to real loads of non-point pollutants and to determine if a realistic method of predicting non-point pollution could be developed.

III. THE MRI MODEL

The Midwest Research Institute (MRI) published a draft final report in July 1975 on "Cost and Effectiveness of Control of Pollution from Selected Nonpoint Sources"[4] for the National Commission on Water Quality. This report described the relative significance of nonpoint sources of pollution of streams in different locations along with the effectiveness and economics of different methods of controlling these nonpoint sources.

A major portion of the MRI study involved pollutants derived from nonpoint sources on agricultural lands. It was, therefore, necessary to predict the amounts of pollutants that would be derived from nonpoint sources in various drainage basins over a large portion of the United States. For this the MRI Model used the Universal Soil Loss Equation[5] to predict sediment inputs and based nutrient loadings on these sediment contributions.

A. Sediment

1. MRI - Universal Soil Loss Equation

The Universal Soil Loss Equation was used as a predictor of sediment loadings in the form:[6]

$$Y(S) = \sum_{i=1}^{n} [A_i \cdot (R \cdot K \cdot L \cdot S \cdot C \cdot P \cdot SD)_i]$$

where: $Y(S)$ = sediment loading of the basin in tons/year

n = number of subareas in acres

A_i = acreage of subarea i

R = the rainfall factor in units of rainfall-erosivity index; EI/year

K = the soil-erodibility factor in tons/acre/EI unit

L = the slope-length factor, (dimensionless)

S = the slope-steepness factor, (dimensionless)

C = the cover factor, (dimensionless)

P = the erosion control practice factor, (dimensionless)

SD = the sediment delivery ratio, (dimensionless)

The meaning of each term in the soil loss equation, methods of determining the values of the terms, and modifications needed to calculate the predicted sediment loadings for the study streams are discussed in the following sections. For a more detailed discussion and the necessary maps, charts and graphs the reader is referred to *Agriculture Handbook No. 282*, U. S. Department of Agriculture, May 1965. (Hereafter referred to as "Handbook".)

a. A_i Area of Subbasin i

In this study it was more convenient to deal with the total area of the drainage basin rather than subareas and to use a

weighted mean of each of the other factors if they were not constant over the whole basin. This does not change the value of the loads calculated from the equation but was easier to work with here. Areas of each basin used in the study were stated in the source material; these were converted from acres to hectares and all measurements are in metric units. Drainage basin areas varied from 1.48 Ha to 11526 Ha.

b. R - Rainfall Factor

The rainfall factor or rainfall erosion index is a term that reflects the relationship of soil loss to rainstorm characteristics. These values were found by locating the drainage basins on a map[7] (Handbook) showing contours of average annual rainfall factor. The map does not cover states west of the Continental Divide, therefore, basins in the far western U. S. were not used here. R values varied from 85 to 250, with a median value of 170.

c. K - Soil Erodibility

The soil erodibility factor is a coefficient expressing the rate of erosion per unit of erosion index (R above) from a unit plot of soil with specific length, slope and surface conditions. The Handbook contains a chart of K values for 23 soils[8]. Some of the soils in the drainage basins appeared in this table, but most did not. When the basin soil was not on the chart it was given a K

value of the soil on the chart deemed to be most like it. This was determined using the *Soil Series of the United States, Puerto-Rico and the Virgin Islands*[9] and comparing taxonomic classifications.

Some source articles did not identify the soil type (series) in the basin. In these cases the soil types was determined from soils maps or from typical soils on the closest areas for which soils maps were available (usually the next county). As a result of these inconsistencies, I have the least confidence in the K factor. The values are, however, the result of a reasonably exhaustive effort. Actual K values varied from 0.08 to 0.48 with a median value of 0.25.

d. L - Slope-Length Factor and S - Slope-Steepness Factor

Slope-length and slope-steepness factors have been experimentally determined for use in the soil loss equation. In actual use, however, it is more convenient to use a combined LS factor. This factor represents the expected ratio of soil loss per unit area of the actual basin to soil loss from a unit plot of specific slope and length.

A graph in the Handbook[10] gives the soil-loss (LS) ratios when entered with percent slope and slope length. Slope length is defined as the distance from the start of overland flow to either point of deposition of suspended particles or to the point where runoff enters a well defined channel.

To determine the LS factor for this study I entered the graph with slope as stated in source articles or as measured from 1:24,000 topographic maps. For map determination of slope an average of four slopes was used for each basin, each slope being determined from a straight line drawn along the line connecting a ridge crest with the stream channel or valley bottom at right angles to the contours.

In no case was slope length given in the references used. Since maps do not show the many small stream channels that cover a basin and since on site evaluation was impossible I chose to approximate the slope length of all basins as 200 feet. This figure was chosen because it is the mean and median value on the Handbook graph excluding extrapolations and because it is taught at the U. S. Army Engineer School, Fort Belvoir as the average slope length to use when no other information is available for determining runoff quantity.

Since L and S are experimental values that require extensive work to determine I have substituted the combined LS factor in the soil loss equation. These LS factors were found from graphical techniques or by using the equation.

$$LS = \sqrt{\lambda}\,(0.0076 + 0.0053\,s + 0.00076\,s^2)$$

where: λ = field slope length in feet

s = percent slope

as given in the Handbook[11]. Actual values of LS varied from 0.4 to 17.6 with a median value of 1.4.

e. C - Cover Factor

The cover factor is a dimensionless ratio that reflects the theoretical effectiveness of the vegetative cover in reducing soil erosion. Values of C for various land use categories are given in the MRI report[12]. The descriptions of the watershed cover given in the source articles enabled cover factors, C, to be designated for each basin. Where several different vegetative covers were present, an area weighted average C was used. Actual cover factors used varied from .05 to .47 with a median value of 0.18.

f. P - Practice Factor

The practice factor is a dimensionless ratio that represents the effectiveness of erosion control practices in reducing erosion. The MRI report assumes that adequate land treatment can reduce erosion by 50 percent. For this study, therefore, practice factors were chosen to be 1.0 (i.e., no reduction) for all basins for which no successful erosion control practice was described or 0.5 (i.e., 50 percent reduction) where such practices are described in source articles. Only three basins were given the lower value of P while twenty were given the higher value.

g. SD - Sediment Delivery Ratio

The sediment delivery ratio is a factor that represents the fraction of soil that enters stream channel based on distance of travel and particle size and texture. The MRI has developed a sediment delivery graph in which SD is a function of the reciprocal of drainage density and soil texture[13]. Soil texture was generally stated in source articles or found in descriptions of the basin soil in the *Soil Series*[14].

Drainage density, on the other hand, has not been recorded and is very difficult to determine from readily available sources. Drainage density is defined as the length of stream channels in a basin divided by the area of the basin and has units of kilometers or miles per square kilometer or square mile. The reciprocal of the drainage density has the units of square kilometers of area divided by kilometer of channel or simply kilometers.

While determining the area of a basin is reasonably easy, accurate measurement of the channel length is not. A given piece of ground is covered with many different channels varying in size from major rivers to very small streams, ditches and depressions. The size of stream that is to be considered in measuring length of channel is nowhere stated and what one uses is more or less individually determined.

Much work was done to determine basin drainage densities; the

most consistent method described below was, however, the one used in this study. The boundaries were delineated on 1:24,000 topographic maps. Drainage densities were determined by measuring the length of all stream channels (both intermittent and permanent) in the basin and dividing by the area as measured by planimetry. In basins that were so small as to not have any channel shown on 1:24,000 maps, I determined the drainage density of the next larger basin of which it was a subbasin and assigned that value to the subbasin. Several source articles did not give sufficient information to locate basins exactly. In these cases an average of four or more basins in the general area was assigned.

Values of SD were then found using the MRI graph, soil texture and drainage density. These varied from .53 to .70. Most values of SD were in the range of .56 ± .03 because most soils were predominantly silt. The one higher value of .70 was due to a difference in soil texture because drainage density was roughly the same as in other samples.

2. Modified Soil Loss Equation

The Universal Soil Loss Equation used in this study is therefore the modified version of the MRI equation below.

$$Y(S) = 2242 \cdot A \cdot R \cdot K \cdot LS \cdot C \cdot P \cdot SD$$

where: $Y(S)$ = sediment loading of the basin, in kilograms per year

A = area of the basin, in hectares

LS = combined length-slope factor, (dimensionless)

C = area weighted average cover factor, (dimensionless)

All other terms are as before.

Using this modified soil loss equation and data developed from source articles (see Table I), the annual load of sediment carried into each of the streams was calculated. These "predicted" values are shown in Table II.

B. Nutrients

1. MRI - Nutrient Loading Functions

The MRI nutrient loading functions are based on the assumption that total nutrient loads can be related to and predicted based on sediment load as determined from the Universal Soil Loss Equation. These loading functions are:[15]

$$Y(NU) = 20 \cdot Y(S) \cdot C_{Nu} \cdot r$$

where: $Y(NU)$ = nutrient load in stream, in pounds/year

$Y(S)$ = sediment load in stream, in tons/year

C_{Nu} = concentration of nutrient in soil, in percent by weight

r = enrichment ratio

$= \frac{\text{nutrients in eroded soil}}{\text{nutrients in uneroded soil}}$

= 4.0 for nitrogen, and 1.5 for phosphorus

These terms and modifications in the equations used for this study are described below.

a. C_{Nu} - Nutrient Concentration in Soil

NITROGEN

Nitrogen concentrations in the basin soils (C_N) were determined from a map in the MRI report[16] which is based on the expression[17]

$$C_N = 0.55e^{-0.08T}(1-e^{-0.005H})$$

where: C_N = nitrogen content of the soil in percent by weight (Note in the MRI report this term is called N_T.)

$$H = \frac{P}{(1 - \frac{RH}{100})SVP_t}$$

P = precipitation, in mm/year

T = annual average temperature, in °C

RH = relative humidity, in percent

SVP_t = saturation vapor pressure at the temperature above, in mm of mercury

$$= 10^{[9.2992 - 2360/(273+T)]}$$

This equation was developed by Jenny in a paper published in 1930[18]. In this paper Jenny attempts to associate the nitrogen content of the soil with the climatic variables of temperature and a humidity factor (the ratio of precipitation to evaporation).

There are several obvious shortcomings in Jenny's methods that make the general application of his equation very questionable. He bases all of his calculations on atmospheric climatic observations when he, in fact, admits that it is actually the soil climate that would logically influence biochemical processes and, therefore, soil nitrogen levels. Probably the most salient shortcoming, however, is that Jenny's equation includes terms ($K_1 = 0.08$, $K_2 = 0.005$ and $C = 0.55$) that are composite values of these same terms determained for several different soil types and in several different climatic zones. His graphs show that these areas and soils obviously have significantly different relationships of temperature and humidity factor to soil nitrogen. It is, therefore, a gross approximation to use average values of the "constants" in the equation (if they are averages) in a general expression for soil nitrogen.

Of the C_N values taken from the MRI map all but two were 0.15; the others were 0.20 and 0.25.

PHOSPHORUS

The phosphorus concentrations of basin soils were determined using a map in the MRI report[19] which was taken from Parker, et. al.[20]. This map gives percent of P_2O_5 in the top foot of the soils over the continental United States (C_p). The map appears in the "Native Soil Fertility" section of the paper of Parker[21] but no reference is made of the original source of the data. The paper does mention in the same section, however, that, "*The fertility of our soils is changing*"[22]. If this is true, it is logical to assume that the map is somewhat inaccurate since it is based on measurements made at least thirty years ago and that some of the soils may have changed significantly in phosphoric acid (P_2O_5) content in that time.

The MRI model also neglects the augmentation of natural soil phosphorus by fertilizer applications. This neglect of fertilization along with the use of thirty year old nature fertility data makes the MRI phosphorus predictions highly suspect. These values were corrected in the calculations so as to give phorphorus rather than P_2O_5 content. Actual values of C_p used varied from 0.07 to 0.20 with a median value of 0.15.

b. r - Enrichment Ratio

This term represents the ratio of nutrient content in eroded

soil to that in uneroded soil. The MRI states that the ratio is 4.0 for nitrogen and 1.5 for phosphorus which suggests that there is four times as much nitrogen and fifty percent more phosphorus in eroded soil (presumably surface layers) than in uneroded soil (lower layers). The source of these ratios was not stated in the MRI report, therefore I cannot comment on their validity.

2. Modified Nutrient Loading Functions

The nutrient loading predictions for the study basins were calculated based on the MRI equation using the sediment loads calculated from the modified Universal Soil Loss Equation described earlier.

Nitrogen Loading Function

$$Y(N) = 89.7 \cdot (A \cdot R \cdot K \cdot LS \cdot C \cdot P \cdot SD \cdot C_N)$$

where: $Y(N)$ = nitrogen load in stream, in kilograms/year

C_N = concentration of nitrogen in soil, in percent by weight

All other terms are as previously described.

Phosphorus Loading Function

$$Y(P) = 14.7 \cdot (A \cdot R \cdot K \cdot LS \cdot P \cdot C \cdot SD \cdot C_p)$$

where: $Y(P)$ = phosphorus load in stream, in kilograms/year

C_p = concentration of P_2O_5 in soil, in percent by weight

All other terms are as previous described.

Using these modified nutrient loading functions and data from source articles (Table I), the predicted annual load of nitrogen and phosphorus in each stream was calculated. These values are shown in Tables III and IV.

The loading functions of the Midwest Research Institute and those modified for use in this study are summarized here for easier reference.

LOADING FUNCTIONS

Functions used by MRI:

Sediment:

Universal Soil Loss Equation

$Y(S)=\sum[A_i(R\cdot K\cdot L\cdot S\cdot C\cdot P\cdot SD)_i]$

Where;

$Y(S)$=Sediment (tons/year)

A_i = Area of subarea i (acres)

R=Rainfall factor

K=Soil-erodibility factor

L=Slope-length factor

S=Slope-steepness factor

Nutrients:

$Y(NU)=20\cdot Y(S)\cdot C_{Nu}\cdot r$

Where;

$Y(NU)$=Nutrient (lb/year)

C_{Nu}=Nutrient in soil (% by wt)

r=Enrichment ratio

=4.0 for nitrogen

=1.5 for phosphorus

TABLE I - DATA FROM SAMPLE BASINS

Watershed Number	Location	A Area (Ha)	R Rainfall Factor	K Soil Erodibility	s Percent Slope	LS Lenght-Slope	P Erosion Practice	DD Drainage Density	1/DD (1/mile)	SD Sediment Delivery	C Cover Factor	C_N % Nitrogen in soil	C_P % P_2O_5 in soil
1	Coshocton Ohio	123	155	.48	8.0	1.4	1	2.101	.469	.57	.145	.15	.15
2	"	17.6	155	.48	15	3.7	1	2.450	.408	.58	.05	.15	.15
3	Treynor Iowa	157.5	170	.33	7.4	1.2	1	1.866	.571	.55	.33	.15	.15
4	"	33.6	170	.33	7.4	1.2	1	1.741	.574	.55	.47	.15	.15
5	Mahantango Pa	771.3	150	.10	4.7	0.75	1	2.018	.506	.56	.178	.20	.10
6	Waynesville NC	1.88	250	.25	37.0	17.6	1	2.800	.362	.59	.1075	.15	.07
7	"	1.48	250	.25	37.0	17.6	1	2.800	.362	.59	.1075	.15	.07
8	Treynor Iowa	30.0	170	.33	7.4	1.2	1	2.503	.399	.57	.47	.15	.15
9	"	33.6	170	.33	7.4	1.2	1	1.741	.574	.55	.47	.15	.15
10	"	43.3	170	.33	7.4	1.2	.5	1.354	.739	.53	.1075	.15	.15
11	"	60.8	170	.33	7.4	1.2	.5	1.354	.739	.53	.47	.15	.15
12	Cave Creek Ky	655	200	.20	4.5	0.7	1	2.087	.479	.70	.115	.15	.20
13	Flat Creek Ky	1459	190	.31	8.1	1.4	1	2.245	.445	.57	.076	.15	.20
14	Plum Creek Ky	8239	195	.31	7.4	1.6	1	2.887	.346	.59	.359	.15	.17
15	McGills Creek Ky	554	205	.31	18.8	5.4	1	2.327	.425	.58	.1097	.15	.17
16	West Bays Fork Ky	1935	200	.10	10.0	1.9	1	1.590	.629	.54	.297	.15	.10
17	Rose Creek Ky	544	200	.20	2.4	0.4	1	2.892	.346	.59	.249	.15	.07
18	Helton Branch Ky	200	200	.08	21.5	6.7	1	2.872	.348	.59	.05	.15	.15
19	Perry Creek Ky	446	250	.20	2.6	0.4	1	2.353	.425	.58	.258	.15	.07
20	Aurora NY	7.8	85	.20	3.0	0.5	1	1.960	.526	.56	.177	.25	.15
21	Salem Fork WV	2155	160	.20	26.0	9.3	1	1.331	.751	.53	.085	-	-
22	Stony Brook NJ	11526	200	.20	3.0	0.45	1	1.532	.653	.54	.209	-	-
23	Sixler Run Pa	3885	125	.10	11.0	2.3	.5	2.052	.487	.56	.109	-	-

C=Cover factor

P=Erosion control practice factor

SD=Sediment delivery ratio

Functions as modified for this study:

Sediment:

$Y(S)=2242 \cdot A \cdot R \cdot K \cdot LS \cdot C \cdot P \cdot SD$

Where;

Y(S)=Sediment (Kg/year

A=Area of basin (hectares)

LS=Length-slope factor (a combination of L & S above)

All other terms as above.

Nutrients:

$Y(N)=89.7 \cdot A \cdot R \cdot K \cdot LS \cdot C \cdot P \cdot SD \cdot C_N$

Where;

Y(N)=Nitrogen (Kg/year)

C_N=Nitrogen in soil (% by wt)

$Y(P)=14.7 \cdot A \cdot R \cdot K \cdot LS \cdot C \cdot P \cdot SD \cdot C_P$

Where;

Y(P)=Phosphorus (Kg/year)

$C_P=P_2O_5$ in soil (% by wt)

C. Some Measures of Sensitivity

In this section the impact of each of the inputs on the loading functions and interrelationships of important terms are discussed. These impacts are determined by possible errors in the terms themselves and by the degree that these errors effect the final loading function calculations. Errors in assigning values to the

terms can be the result of:

(1) errors in physical measurements;

(2) insufficient available data necessitating the use of approximations, and assumptions upon which these are based;

(3) errors from the use of theoretical relationships that are either wrong or inaccurate;

(4) errors in map representation of complex natural properties, map location and interpolation; and

(5) natural changes in physical properties.

1. A - Area of Basin

This, like most other inputs, is simply one of a linear set of terms whose product is the loading function. Any error in the actual area therefore produces a similar error in both relative magnitude and direction in each of the loading functions. The nature of this term is such, however, that differences between actual area and that measured would be expected to be small. In other words, area is easy to measure with appropriate accuracy and therefore does not introduce significant errors in the loading functions.

2. R - Rainfall Factor

Rainfall factor is a linear input, the impact of which is of the same magnitude and direction as any difference between actual

and measured values. The source of this data is, however, a map on which basins can be accurately located. The only errors that can result are those of interpolation between rainfall contours or original errors on the map. Since the MRI used the same map, presumably errors in it have been included, and compensated for, in the model. Errors in finding accurate rainfall factor values are therefore minimal.

3. K - Soil Erodibility

Soil erodibility is a linear input that introduces linear errors if not accurately evaluated. However, as discussed previously, the soil erodibility is a very difficult term to determine accurately. Evidence of this is the fact that one soil series (Cecil) has no less than four different K values in the Handbook[23]. These values are significantly different within the possible range of values of K. The range of possible values is limited, however, but the value of K could be in error by a factor of from 10 to 20. This term then has a significant impact on loading functions and is a likely source of sizable errors.

4. L - Slope-Length

Slope-length as used in the modified loading functions is nonlinear. It is used with percent slope to enter a graph giving a

combined LS term which is linear. Information on slope length was not available and, as discussed previously, a length of 200 feet was used in each case. This, of course, introduces errors inasmuch as slope length is not everywhere constant. Errors in L are probably not as large as K above, however. Blong and Ryde[24] found in New Zealand that the mean slope length of 104 slopes was 222 feet with a standard deviation of 138 feet. These L would probably be off by less than a factor of one.

The effect of L errors would also be small. At a constant slope of 11.5 percent (the mean of all basins in the study), a ten percent increase in L from 200 feet to 220 feet, resulted in only a four percent increase in the LS factor and thus in loading functions.

5. s - Slope Gradient

Like L, the percent slope is a nonlinear input used to find the LS factor in the loading functions. Errors in determining slope should be small because it is a physical term that can be easily measured on the ground or from a map. The only foreseeable errors are in not measuring enough individual slopes to accurately determine the mean slope for the basin.

The effect of slope errors on the LS factor would be large, however. At a constant slope length of 200 feet (as was used here

for all basins), a ten percent increase in slope, from 11.5 to 12.65, resulted in a 14 percent increase in LS and in loading functions. Since, however, slope gradient probably increases as slope length decreases the tendency is for the two terms to buffer errors in LS. I would then not expect the slope length and slope gradient to introduce sizable errors in the loading functions.

6. C - Cover Factor

Cover factor is also a linear term which will cause errors in loading functions in the same direction and relative magnitude as errors in its own value. The MRI generally states C factors in enough detail to choose accurate ones for each basin. Errors are introduced by inadequate descriptions of vegetation in the source references or through inaccurate measures of the areas of different vegetation types. Adequate descriptions were available for the sites studied, therefore, errors in C should be minimal in this study.

7. P - Practice Factor

The practice factor, another linear term, was constrained by the MRI to values of either 1.0 or 0.5 by implication. The only method to accurately determine the actual effectiveness of erosion control (the practice factor) is through field tests and

experimentation. Had the MRI not constrained P, its determination would have been extremely difficult. With P constrained however, in this model, the only sources of errors are inadequate description of erosion control in the references. The degree to which the references do not note erosion control is not known but for most basins the errors can be a doubling of loading function values at the worst.

No range of measured practice factors is given here but theoretically it could range from 1.0 as in most basins here, to zero which would indicate no actual sediment load from a basin. As constrained by the MRI, however, practice factor is relatively easy to determine and should not introduce more than moderate errors.

8. DD - Drainage Density

Drainage density is a nonlinear input used to determine sediment delivery ratio (SD), which is linear in the loading functions. As discussed earlier, drainage density was found using 1:24,000 topographic maps. This method certainly underestimates DD because for the constant basin area only the larger rivers and streams were measured. For a given soil texture, however, changes in drainage density made small changes in the SD. The exponent of DD in the equation for SD for silty soils[25] is 0.1784. Therefore, the impact of a change in DD on SD and thus on the loading functions is small.

In addition, more accurate (that is higher) DD values will cause loading predictions to increase. Since, as will be seen later, all predictions are greater than measured loads, the results of more accurate drainage density determinations are less accurate nonpoint load predictions and a reduction of the utility of these loading functions as predictive tools.

9. C_{Nu} - Nutrient Concentration in Soil

Nutrient concentrations are also linear terms in the loading functions. The adequacy of the maps and methods used to draw them (Jenny; Parker, et. al.) have been discussed previously. The MRI models are based on these maps however, therefore, any errors in the loading functions can come from interpolation or location of basins accurately. Such errors should be minimal and loading functions can be expected to be affected little by nutrient concentration errors.

IV. BASIN DATA AND ANALYSIS

A. Sediment

Since the MRI model is based upon the ability of the Universal Soil Loss Equation to predict the actual sediment load of a stream, I first compared measured with predicted sediment loads. Data for sediment loads was initially available on only six streams and all of these were in one area of Iowa. Therefore, three streams in other areas were added where published sediment load data existed and where sufficient information to apply the soil loss equation was available. Predicted and measured sediment loads in terms of total load and load per unit area are shown for all nine streams in Table II.

As may be seen from Figure 1 the measured total sediment load in all but one of the streams is below that predicted and in most cases about one order of magnitude lower. A linear regression line (not straight on log paper) of actual against predicted sediment is also shown. The slope of this line (.08) reflects the tendency of the measured sediment load to be about one-tenth of the predicted value. Figure 2 shows a linear regression line of the log of measured sediment load against the log of the predicted load and again indicates that measured sediment is significantly lower than that predicted by the Universal Soil Loss Equation.

TABLE II - PREDICTED & MEASURED SEDIMENT LOADS

	Location	Area (Ha)	Predicted Sediment (Kg)	Predicted Sediment (Kg/Ha)	Measured Sediment (Kg)	Measured Sediment (Kg/Ha)
3	Treynor Iowa	157.5	4313941	27390	169736	1078
4	"	33.6	1310741	39010	777193	23131
8	"	30.0	1234139	41135	1530436	51015
9	"	33.6	1310741	39010	1124013	33453
10	"	43.3	186148	4299	51710	1194
11	"	60.8	1142784	18796	163295	2686
21	Salem Fork WV	2155	7576280	1950	870912	224
22	Stony Brook NJ	11526	52494691	4554	7983360	693
23	Bixler Run Pa	3885	64914776	30123	3175200	1474

FIGURE 1 - MEASURED VS PREDICTED AVERAGE ANNUAL SEDIMENT LOAD
with arithmetic linear regression.
(Watershed numbers printed near points on graph.)

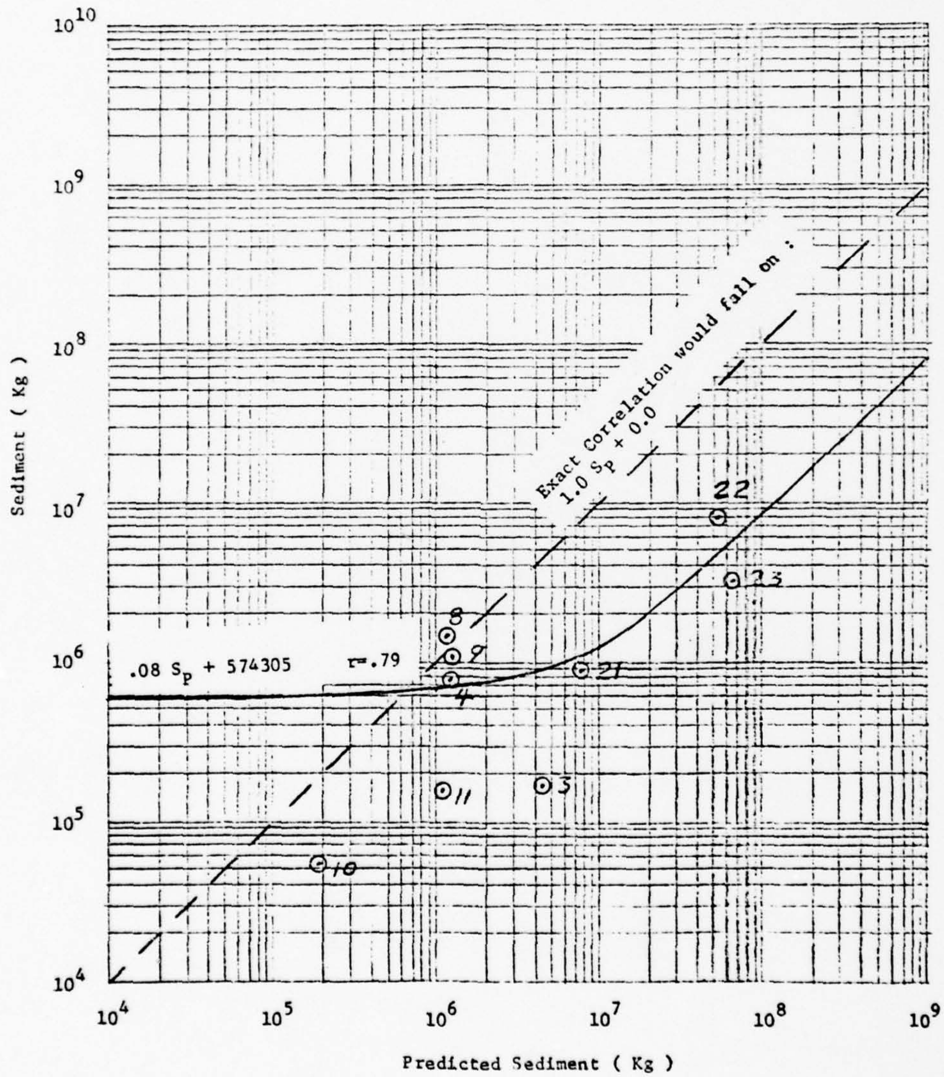


FIGURE 2 - MEASURED VS PREDICTED AVERAGE ANNUAL SEDIMENT LOAD with logarithmic linear regression. (Watershed numbers printed near points on graph.)

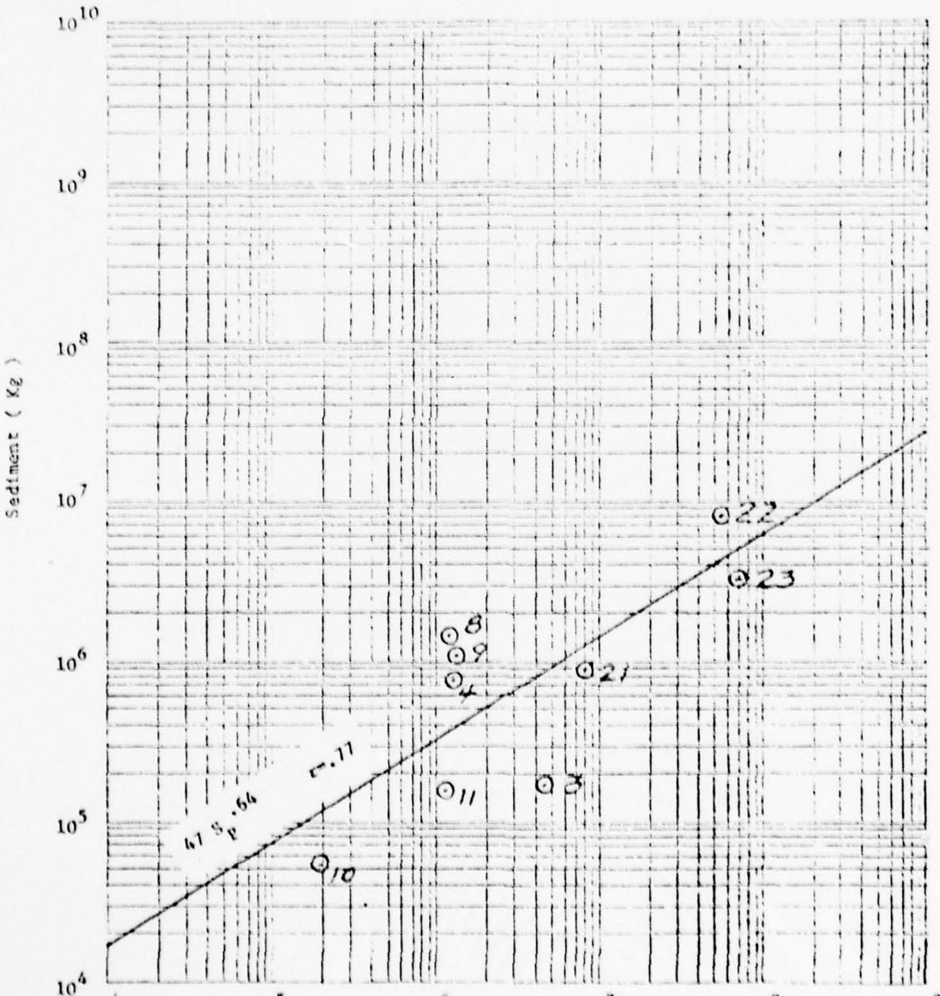
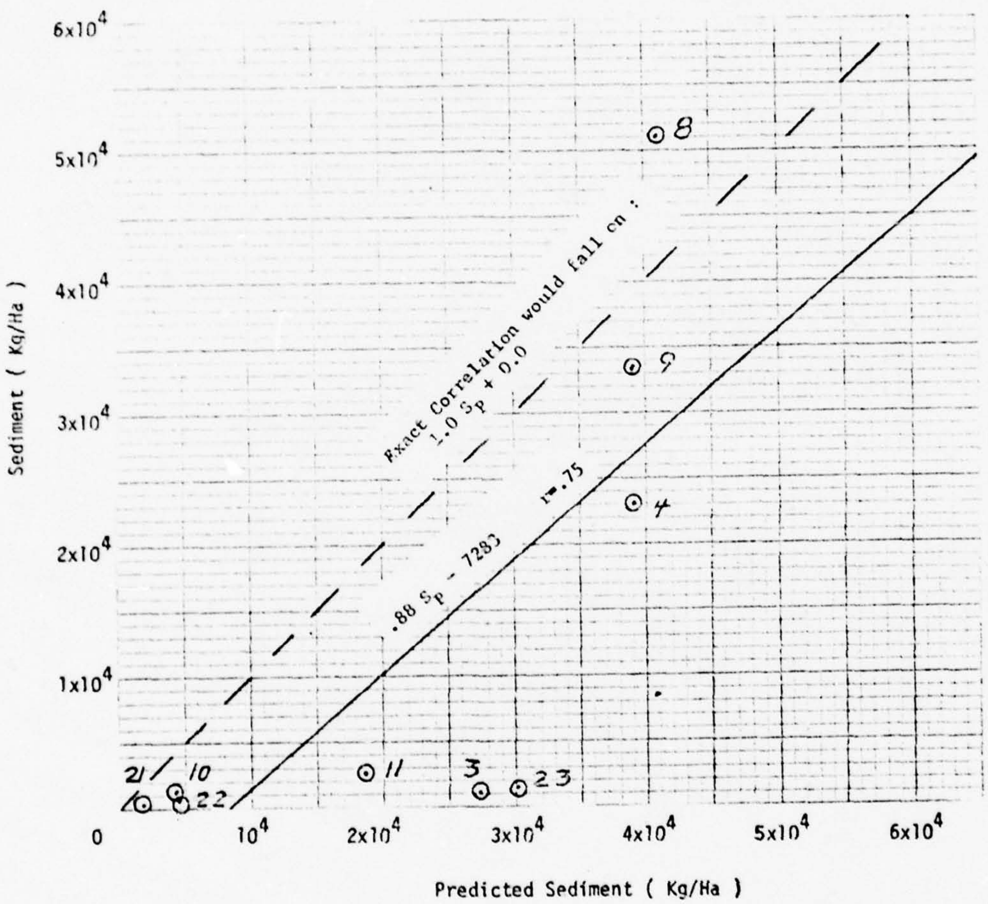


FIGURE 3 - MEASURED VS PREDICTED AVERAGE ANNUAL SEDIMENT LOAD PER HECTARE with arithmetic linear regression. (Watershed numbers printed near points on graph.)



The measured load and predicted load per unit area are plotted on Figure 3. Here the linear regression line is again below the line for an exact correlation. Of significance is the fact that six of the nine points lie along a line (not drawn) that would represent a slope of one tenth that predicted.

While very little data is used here and conclusions must be tentative, it appears that sediment load predicted by the Universal Soil Loss Equation is too high. It may give an upper bound to actual sediment loads. A majority of watersheds apparently have sediment loads roughly one tenth of that given by the soil loss equation.

B. Nutrients

1. Total Nutrient Loads

The MRI nutrient equations are intended to predict the total amount of nutrients contributed to a stream on an annual basis. Total load is the sum of both the nutrient in solution and that bound to the sediment. The MRI bases its use of the Universal Soil Loss Equation as the foundation of the nutrient models on the assumption that the majority of nutrient load is associated with the sediment. For this study, data on total nutrient load is limited. In fact, figures were found for only six streams giving total nitrogen load and for only two streams for total phosphorus. In addition, all of these streams are from one area (Treynor, Iowa) so that conclusions

drawn from such data must be limited.

From the tabulated data for total nitrogen (Table III) a graph was drawn (Figure 4) showing predicted total nitrogen load against the measured total load. A linear regression was performed to find the best straight line that could be fit to the points and the linear correlation. These are shown on the graph and indicate that the best fit line is almost horizontal (that is, large intercept and very shallow slope). This would mean that the actual total nitrogen load is independent of predicted load. The correlation of the points to the line is only .41, however, which indicates that the linear regression line and the data points are not closely related either.

From the graph (Figure 4), it appears that most of the data points fall close to a line on which the predicted total nitrogen is ten times the measured total nitrogen. Such a line parallels the dashed line on the graph and lies one log cycle below it. The implication is that actual total nitrogen load may generally be about one tenth of the MRI prediction. If this is, in fact, true for a great many drainage basins, then the MRI equation can be used to predict total nitrogen load simply by taking one tenth of the result. This study has far too few data points to make such a determination but additional work on this prospect may be warranted.

In addition to predicted values, measured total nitrogen was plotted against area of the basin (Figure 5). The linear regression

TABLE III - PREDICTED & MEASURED TOTAL NITROGEN LOADS

	Location	Area (Ha)	Predicted Nitrogen N_{TP}(Kg)	Predicted Nitrogen N_{TP}(Kg/Ha)	Measured Nitrogen (Kg)	Measured Nitrogen (Kg/Ha)
1	Coshocton Ohio	123	14247.3	115.8		
2	"	17.6	1890.5	107.4		
3	Treynor Iowa	157.5	25893.2	164.4	962.3	6.11
4	"	33.6	7867.3	234.1	1221.0	36.34
5	Mahantango Penn.	771.3	15516.9	20.1		
6	Waynesville N.C.	1.88	1764.8	938.7		
7	"	1.48	1389.3	938.7		
8	Treynor Iowa	30.0	7407.6	246.9	1189.2	39.6
9	"	33.6	7867.3	234.1	841.7	25.1
10	"	43.3	1117.3	25.8	101.5	2.3
11	"	60.8	6859.2	112.8	184.8	3.0
12	Cave Creek Ky.	655	19864.6	30.3		
13	Flat Creek Ky.	1459	70124.7	48.1		
14	Plum Creek Ky.	8239	2271019.8	275.7		
15	McGills Creek Ky.	554	162756.1	293.8		
16	West Bays Fork Ky.	1935	158671.3	82.0		
17	Rose Creek Ky.	544	17205.0	31.6		
18	Helton Branch Ky.	200	8510.0	42.6		
19	Perry Creek Ky.	446	17959.6	40.3		
20	Aurora N.Y.	7.8	147.4	18.9		

TABLE IV – PREDICTED & MEASURED TOTAL PHOSPHORUS LOADS

	Location	Area (Ha)	Predicted Phosphorus P_{TP} (Kg)	Predicted Phosphorus P_{TP} (Kg/Ha)	Measured Phosphorus (Kg)	Measured Phosphorus (Kg/Ha)
1	Coshocton Ohio	123	2332.2	19.0		
2	"	17.6	309.4	17.6		
3	Treynor Iowa	157.5	4469.7	26.7	70.40	0.45
4	"	33.6	1287.8	38.3	32.49	0.967
5	Mahantango Penn.	771.3	1270.0	1.65		
6	Waynesville N.C.	1.88	134.8	71.7		
7	"	1.48	106.1	71.7		
8	Treynor Iowa	30.0	1212.5	40.4		
9	"	33.6	1287.8	38.3		
10	"	43.3	182.9	4.2		
11	"	60.8	1122.8	18.5		
12	Cave Creek Ky.	655	4335.6	6.6		
13	Flat Creek Ky.	1459	15305.2	10.5		
14	Plum Creek Ky.	8239	421314.9	51.1		
15	McGills Creek Ky.	554	30194.2	54.5		
16	West Bays Fork Ky.	1935	17315.5	8.9		
17	Rose Creek Ky.	544	1314.3	2.4		
18	Helton Branch Ky.	200	1393.0	7.0		
19	Perry Creek Ky.	446	1371.9	3.1		
20	Aurora N.Y.	7.8	14.5	1.9		

FIGURE 4 - MEASURED VS PREDICTED AVERAGE ANNUAL TOTAL NITROGEN LOAD with arithmetic linear regression. (Watershed numbers printed near points on graph.)

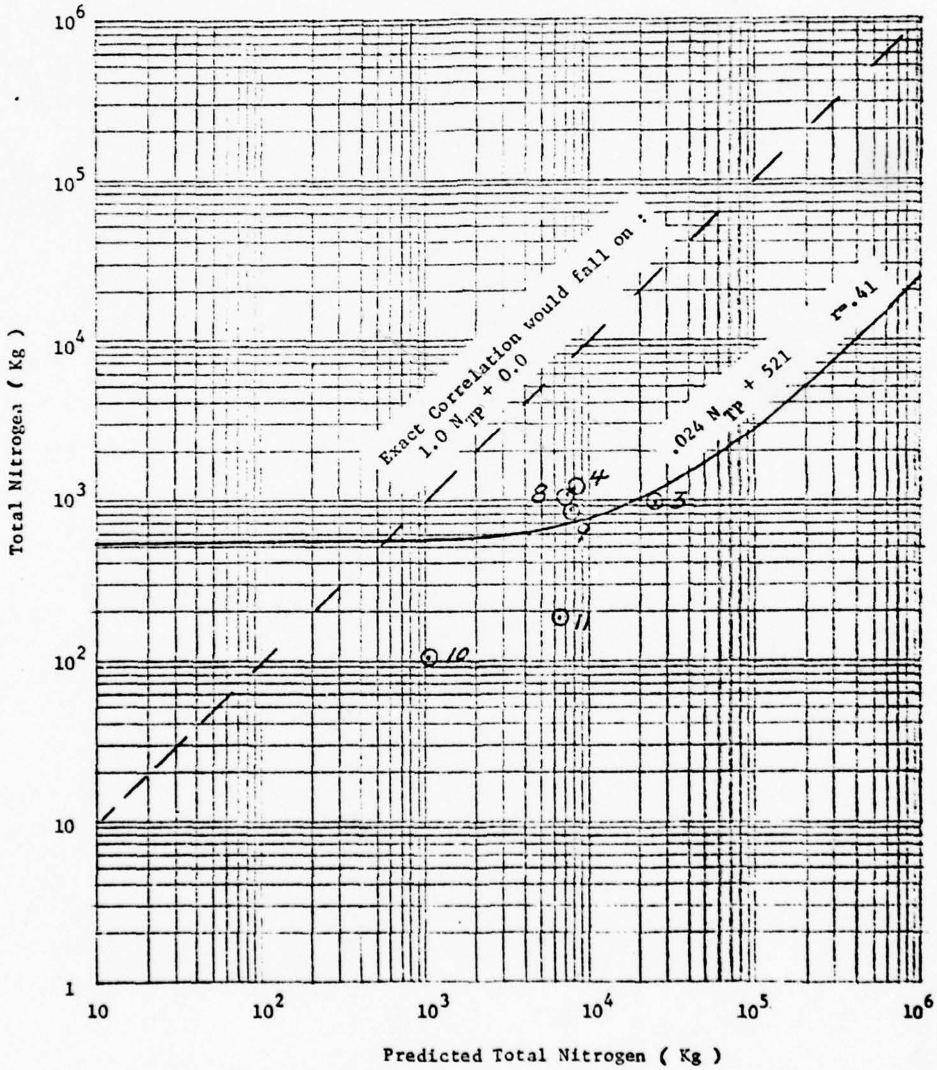
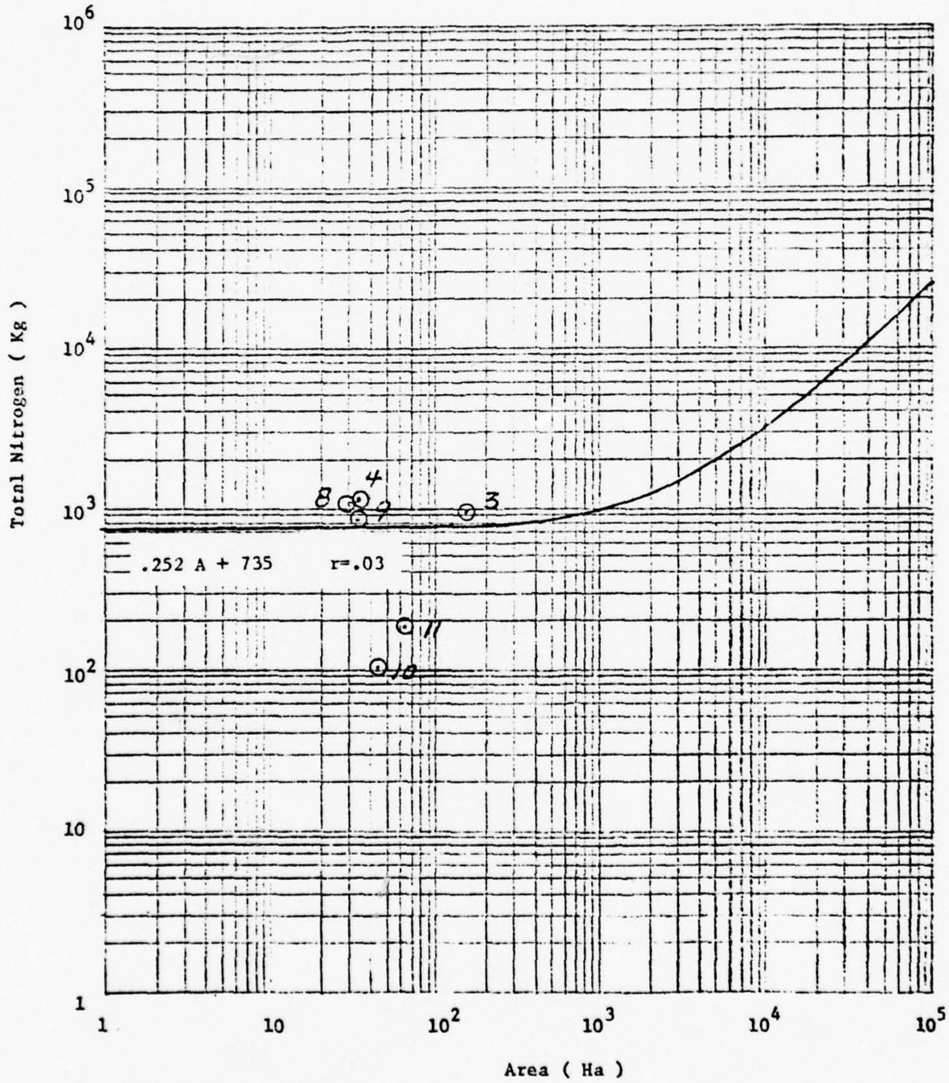


FIGURE 5 - MEASURED AVERAGE ANNUAL TOTAL NITROGEN LOAD VS AREA
with arithmetic linear regression.
(Watershed numbers printed near points on graph.)



is shown, but correlation is very poor. For this reason a relation of total nitrogen to area was not pursued further. As will be seen later, there is a relation of soluble nitrogen to area but no such dependence is seen for total nitrogen.

As was mentioned only two drainage basins in this report give data on total phosphorus load. Because of the lack of data no analysis was done for total phosphorus. For the two available points the MRI equation predicts a total phosphorus load 40 to 60 times the measured load.

2. Soluble Nutrient Loads

The major emphasis in this study is on soluble nutrient loads. It is the soluble nutrients that are the major causes of water pollution problems. Most algae use nutrients in the soluble form being for the most part unable to take them directly from the sediment. The only importance of the nutrients in the sediment is that they can act as a reservoir to resupply those in solution. Since it is doubtful that sediment bound nutrients would increase the concentration of those in solution but would rather buffer any decreasing trend they are of less immediate concern. The second reason for concentrating on soluble nutrient loads is that it is these on which I have been able to collect the vast majority of data. Of the 23 drainage basins in source articles, 19 have soluble nitrogen data

and 16 have soluble phosphorus data.

a. Forms of Soluble Nitrogen

Early in the study I found that all of the source articles presenting nitrogen data reported it as soluble nitrate (NO_3^-) nitrogen and most also reported total soluble nitrogen. Since the MRI model does not differentiate between the forms of nitrogen it was necessary to determine if data could be generated for all streams in terms of total soluble nitrogen.

To do this I calculated the ratio of total soluble nitrogen to soluble nitrate (actually NO_3^- + NO_2^-) nitrogen for the eleven streams for which data was available on both forms. These ratios are shown on Figure 6. It seems clear that for the great majority of streams the ratio of the total to NO_3^- forms is nearly constant. Therefore an average ratio for the elevel streams was calculated and this ratio was used to find the total soluble nitrogen load for the streams reporting only nitrate load. Loads so calculated are indicated on Table V.

As a matter of interest similar calculations were made comparing ratios of total nitrogen to total soluble nitrogen. The results shown on Figure 7 are inconclusive, however.

FIGURE 6 - RATIO OF SOLUBLE NITROGEN TO SOLUBLE NITRATE NITROGEN

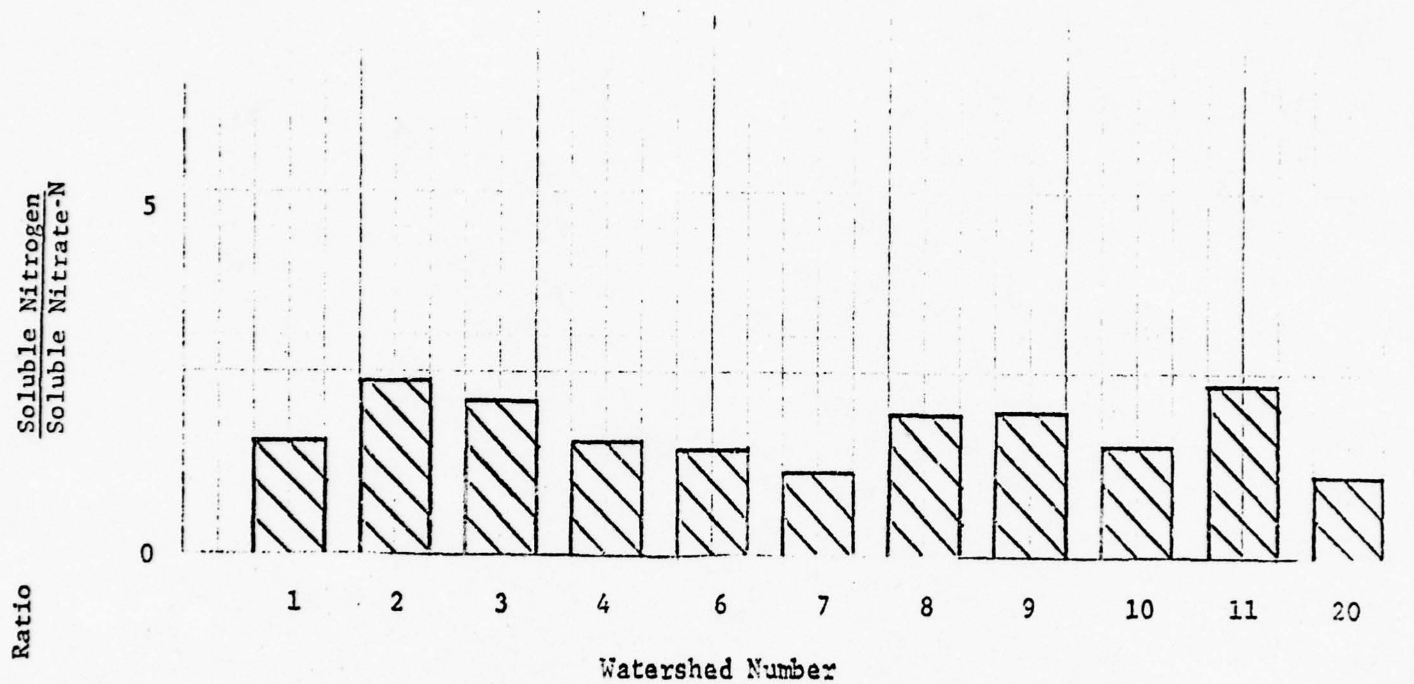
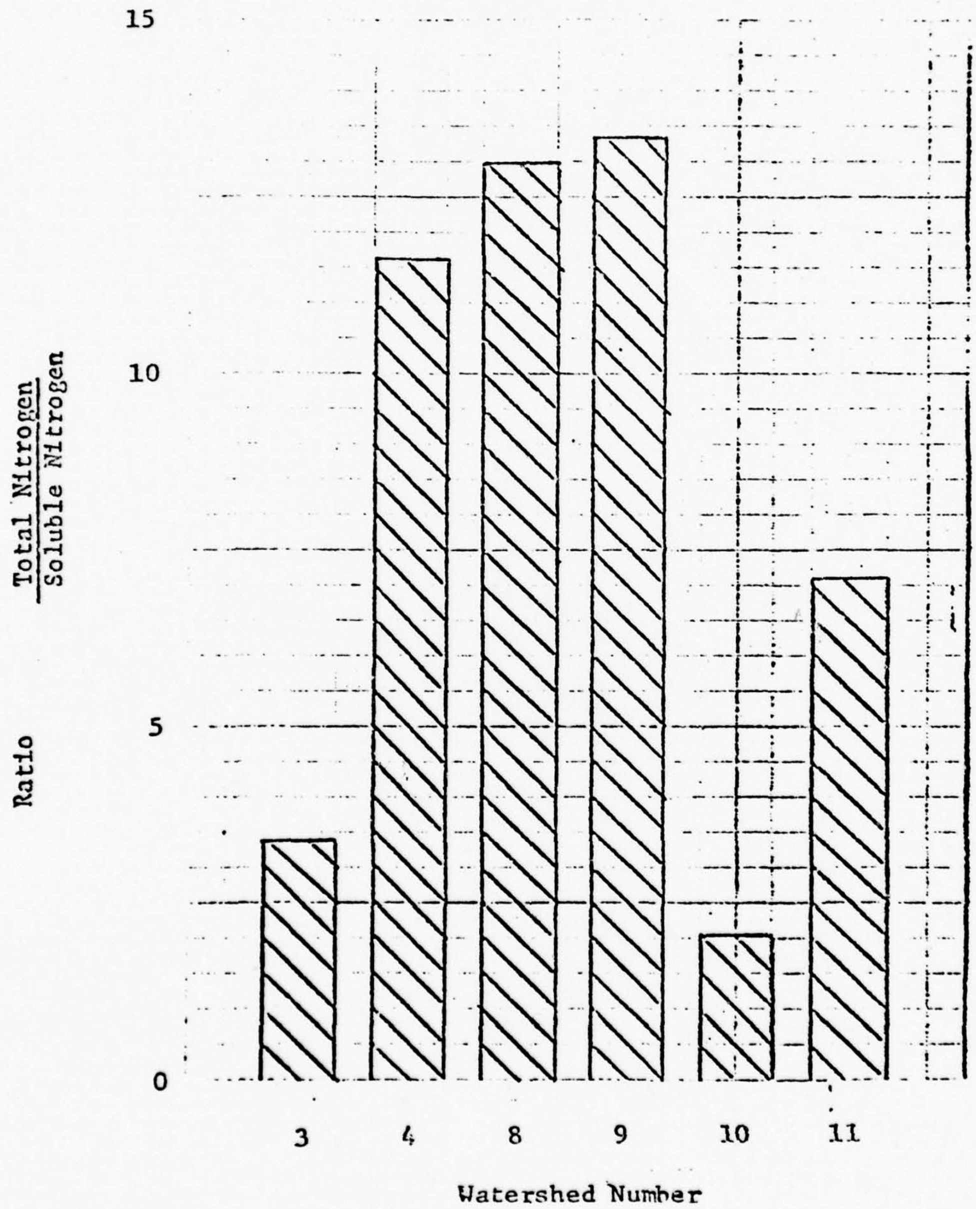


FIGURE 7 - RATIO OF TOTAL NITROGEN TO SOLUBLE NITROGEN



b. MRI Model as a Predictor of Soluble Nutrients

For the remainder of this essay I will discuss nitrogen and phosphorus together as the analysis and results were similar. The data points of measured soluble nitrogen and phosphorus were plotted against the total predicted loads of these nutrients. These plots are on Figures 8 and 9 and both show two linear regression lines. The first line is the best fit straight line (not straight here because log paper was needed to show all points) to all of the points while the second is the best fit to all points less the one extreme point on each graph. The right-hand side of the equations for each line is printed near it on these and all other graphs with the simple linear correlation (r) which is a measure of how well the data point distribution is represented by the regression line.

The linear regression line of measured to predicted data would have a slope of unity, a zero intercept and an exact positive correlation ($r = 1.0$) if the model predicts the exact nutrient value that is measured. The accuracy of the model and its utility can be judged by the closeness of the actual linear regression to that of a perfect predictor described above. The slope parameter may be relaxed and a good predictive tool still be shown if the other two parameters are close to ideal. The various models and prospective prediction terms in this study are all evaluated based on these criteria. Correlation must be relatively high and positive, the intercept should be

TABLE V - MEASURED AVERAGE ANNUAL SOLUBLE NITROGEN & NO_3^- -N LOADS

	Location	Area (Ha)	Measured Soluble Nitrogen (Kg)	Measured Soluble Nitrogen (Kg/Ha)	Measured Soluble NO_3^- N (Kg)	Measured Soluble NO_3^- N (Kg/Ha)
1	Coshocton Ohio	123	607.9	4.94	400.37	3.26
2	"	17.6	43.1	2.45	18.19	1.03
3	Treynor Iowa	157.5	286.7	1.82	133.88	0.85
4	"	33.6	104.8	3.12	69.55	2.07
5	Mahantango Penn.	771.3				
6	Waynesville N.C.	1.88	6.17	3.28	4.63	2.36
7	"	1.48	17.88	12.08	15.30	10.34
8	Treynor Iowa	30.0	91.5	3.05	50.70	1.69
9	"	33.6	63.5	1.89	32.59	0.97
10	"	43.3	49.5	1.14	32.91	0.76
11	"	60.8	25.5	0.42	10.91	0.18
12	Cave Creek Ky.	655	23359.4*	36.43*	13479.9	20.58
13	Flat Creek Ky.	1459	15861.0*	10.87*	8961.0	6.14
14	Plum Creek Ky.	8239	110002.3*	13.35*	62148.2	7.54
15	McGills Creek Ky.	554	4482.5*	8.09*	2532.5	4.57
16	West Bays Fork Ky.	1935	19934.6*	10.30*	11262.5	5.82
17	Rose Creek Ky.	544	14603.0*	26.85*	8250.3	15.17
18	Helton Branch Ky.	200	514.7*	2.57*	290.8	1.45
19	Perry Creek Ky.	446	3456.3*	7.75*	1952.7	4.38
20	Aurora N.Y.	7.8	31.7	4.06	27.65	3.54

* Calculated based on average ratio of Total N / NO_3^- N =1.77

FIGURE 8 - MEASURED AVERAGE ANNUAL SOLUBLE NITROGEN VS PREDICTED TOTAL NITROGEN with arithmetic linear regressions. (Watershed numbers printed near points on graph.)

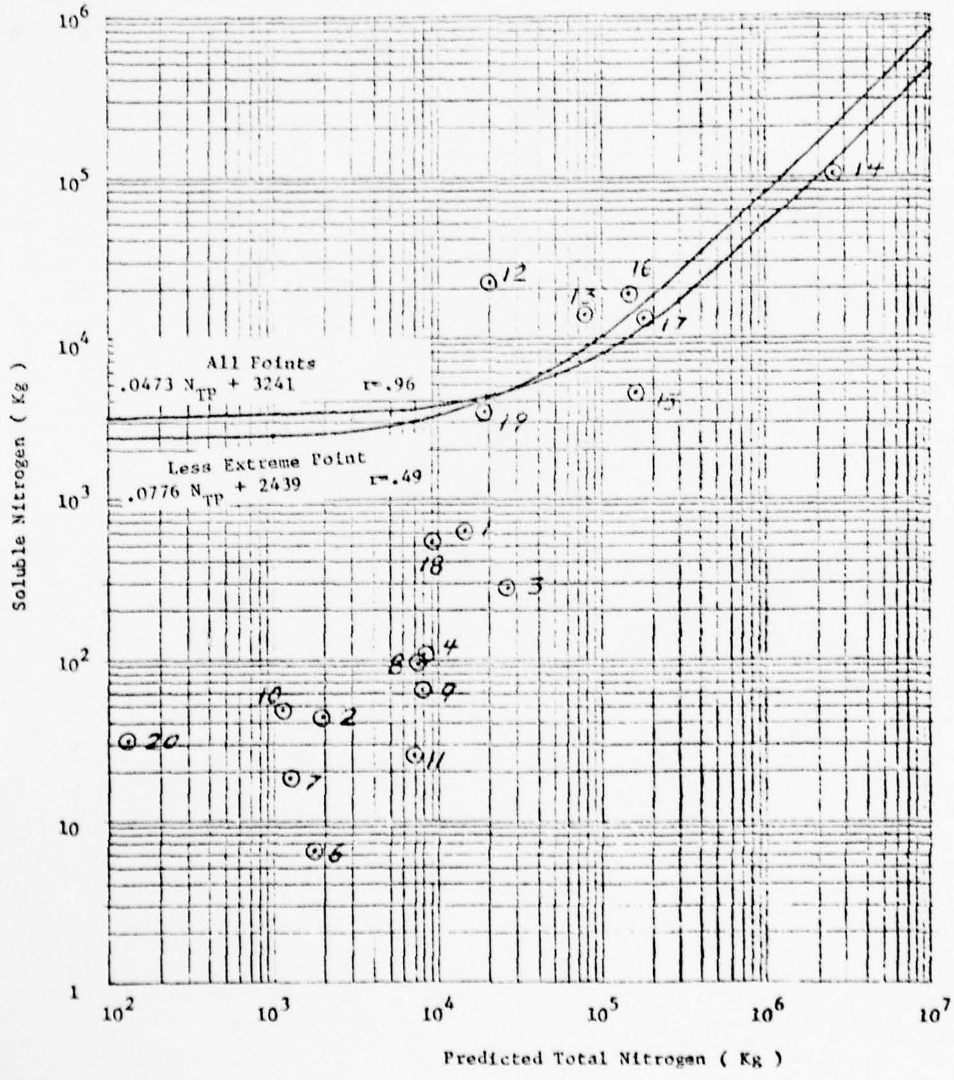
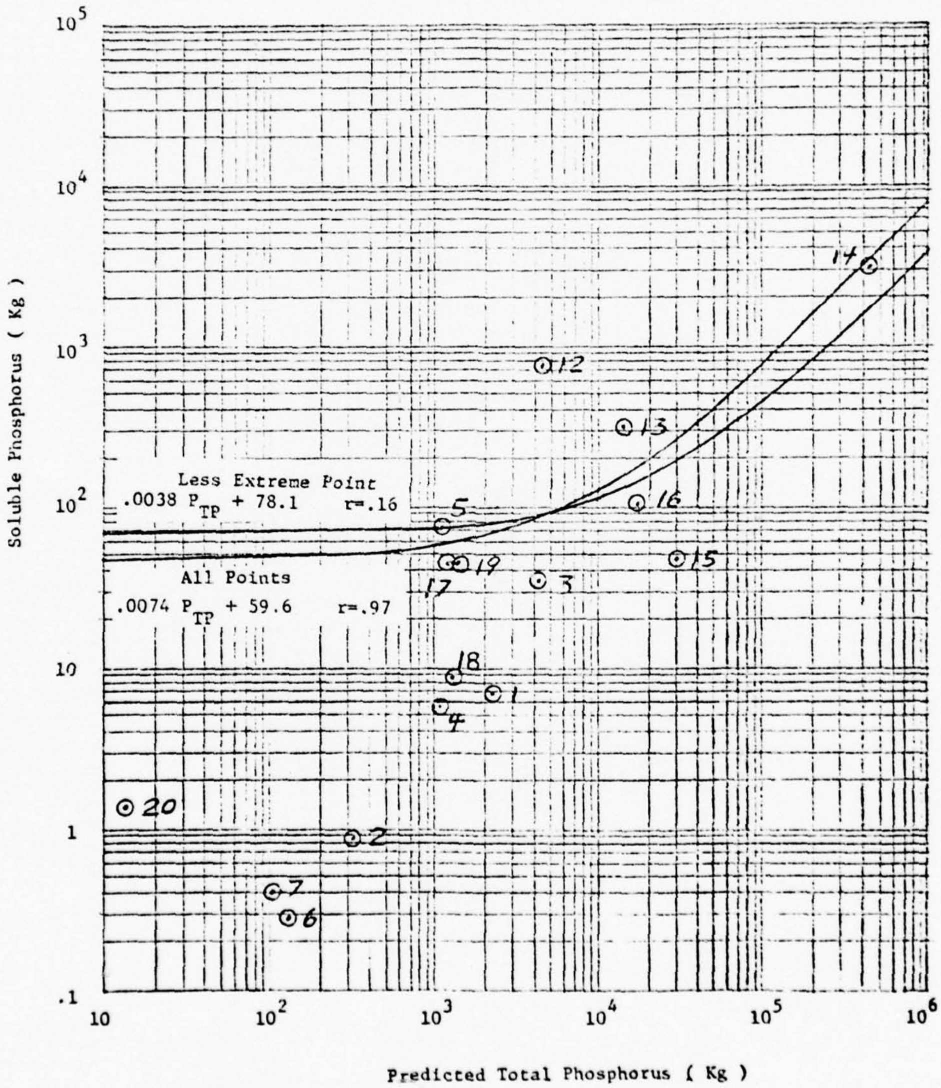


TABLE VI - MEASURED AVERAGE ANNUAL SOLUBLE PHOSPHORUS LOADS

	Location	Area (Ha)	Measured Soluble Phosphorus (Kg)	Measured Soluble Phosphorus (Kg/Ha)
1	Coshocton Ohio	123	6.863	0.056
2	"	17.6	0.836	0.048
3	Treynor Iowa	157.5	36.94	0.235
4	"	33.6	5.81	0.173
5	Mahantango Penn.	771.3	75.60	0.098
6	Waynesville N.C.	1.88	0.28	0.149
7	"	1.48	0.40	0.270
8	Treynor Iowa	30.0		
9	"	33.6		
10	"	43.3		
11	"	60.8		
12	Cave Creek Ky.	655	766.4	1.170
13	Flat Creek Ky.	1459	315.5	0.216
14	Plum Creek Ky.	8239	3166.1	0.384
15	McGills Creek Ky.	554	47.9	0.086
16	West Bays Fork Ky.	1935	116.4	0.060
17	Rose Creek Ky.	544	48.2	0.089
18	Helton Branch Ky.	200	8.87	0.044
19	Perry Creek Ky.	446	48.47	0.109
20	Aurora N.Y.	7.8	1.49	0.191

FIGURE 9 - MEASURED AVERAGE ANNUAL SOLUBLE PHOSPHORUS VS PREDICTED TOTAL PHOSPHORUS LOAD with arithmetic linear regressions. (Watershed numbers printed near points on graph.)



relatively close to a zero value. The slope should be near unity for the model to be predictive as it appears, however if the other criteria are good, the addition of a coefficient to the predictive model can adjust the slope to near unity.

When the utility of the MRI predictions are judged based on the above measures they are seen to be poor predictors of soluble nutrient load. In the case of both nitrogen and phosphorus the slope of the regression lines are so shallow as to not approach an actual data point or materially increase past the intercept value until the independent variable has a value of approximately 10^4. These lines in no way come close to the majority of points, especially on the lower end of the range.

I suspected that the one large basin represented by the extreme point on the graph was dominating the characteristics of the regression lines and the high correlations. This is the reason that regressions were made leaving out this extreme point on these and other plots in the study. As can be seen, on these two plots the slope and intercept were not markedly changed by omitting the extreme point, but the correlations were reduced sharply.

c. *Impact of the Terms in the MRI Model*

A study of the variability of the individual terms in the MRI model and the variables influencing these terms indicated that it

was possible that even though the MRI model was not an extremely useful predictor of soluble nutrient load that one or more of the input factors to the model might be closely related to load and therefore useful as predictive tools.

The large range of drainage area here made it extremely unlikely that any term would be a useful predictor of soluble nutrient load if it were used independent of drainage area. For this reason all terms analyzed for predictive properties were either used in combination with drainage area to test for total soluble load prediction, or used independent of area to test for soluble load per unit area. The variables and combinations of variables tested along with their slopes, intercepts and simple linear correlations are summarized in Tables VII and VIII. All sets of variables that include drainage area have high correlations with measured loads of soluble nutrients. When area is omitted, as in the plot of a single variable against soluble nutrient load per unit area, the correlations are generally much poorer and in many cases negative.

The notable exception to the above is the sediment delivery (SD) variable which has a high correlation to both soluble nitrogen and soluble phosphorus load per unit area. Because of this it was decided to concentrate on the usefulness of area (A) and the combination of area and sediment delivery ratio (A x SD) as predictive tools. Also included was the combination of area and drainage

TABLE VII – SEDIMENT & NITROGEN ARITHMETIC LINEAR REGRESSIONS & CORRELATIONS

INDEPENDENT VARIABLE	vs DEPENDENT VARIABLE	LINEAR REGRESSION & CORRELATION SLOPE	INTERCEPT	CORRELATION
Pre N_T	N_T	.0240	521.1	.4135
Area	"	.2522	735.0	.0252
Area	N_S	13.26	13.66	.9849
Area	NO_3^- N_S	7.461	42.43	.9846
Pre N_T	N_S	.0473	3241.	.9625
Pre N_T	NO_3^- N_S	.0267	1726.	.9625
DD x Area	N_S	4.635	1201.	.9836
SD x Area	"	22.60	104.1	.9878
C x Area	"	36.64	2079.	.9751
LS x Area	"	7.834	-8.058	.9483
S x Area	"	1.703	-215.5	.9576
R x Area	"	.0667	580.5	.9711
K x Area	"	42.73	1427.	.9755
Pre N_T/Ha	N_S/Ha	-.0037	8.882	-.1074
DD	"	5.461	-3.925	.3015
SD	"	201.6	-107.7	.7961
C	"	-12.56	11.04	-.2097
LS	"	-.1653	8.694	-.0931
S	"	-.1530	9.916	-.1687
R	"	.0687	-4.737	.2869
K	"	-30.45	16.69	-.3429
Pre Sed	Sed	.0794	574305	.7899
Pre Sed/Ha	Sed/Ha	.8750	-7283	.7508

TABLE VIII - PHOSPHORUS ARITHMETIC LINEAR REGRESSIONS & CORRELATIONS

INDEPENDENT VARIABLE	vs DEPENDENT VARIABLE		LINEAR REGRESSION & CORRELATION SLOPE	INTERCEPT	CORRELATION
Area	P_S		.3718	-28.06	.9503
Pre P_T	"		.0074	59.60	.9694
DD x Area	"		.1327	-26.68	.9729
SD x Area	"		.6426	-64.60	.9662
C x Area	"		1.040	11.49	.9602
LS x Area	"		.2210	-57.61	.9214
S x Area	"		.0479	-64.76	.9249
R x Area	"		.0019	-41.72	.9417
K x Area	"		1.231	-11.69	.9740
Pre P_T/Ha	P_S/Ha		-.0002	.2160	-.0197
DD	"		-.0204	.2523	-.0324
SD	"		6.453	-3.536	.8486
C	"		-.0697	.2245	-.0314
LS	"		-.0130	.3024	-.2682
S	"		-.0037	.2561	-.1510
R	"		.0008	.0941	.1244
K	"		-.1831	.2584	-.0798

density (A x DD) as this combination has especially high correlation to soluble loads and because drainage density and sediment delivery ratio on a given watershed are highly correlated.

(1) Area

The relationship between area and soluble nutrient loads is shown on Figures 10 and 11. The nutrient load increases with increasing area. Correlations are high between area and soluble load and generally the slopes of the regression lines quickly overcome the intercept value and closely follow most data points. When the extreme point is neglected on each graph the correlation is poorer, although still high especially for nitrogen.

(2) Area x Sediment Delivery

The relationship between the product of area times sediment delivery and soluble nutrient loads are shown on Figures 12 and 13. For the nitrogen graph the regression line fits the data very well, has a high correlation, and is hardly changed when the extreme point is neglected. The phosphorus plot is much less satisfying, however. The linear regression line has a relatively large negative intercept. Also the omission of the extreme point greatly changes the slope of the line and reduces the correlation.

In order to examine the relation of sediment delivery ratio to nutrient loads more closely, plots were made of the sediment delivery against the soluble nutrient load per unit area. These are shown on

FIGURE 10 - MEASURED AVERAGE ANNUAL SOLUBLE NITROGEN VS AREA
with arithmetic linear regressions.
(Watershed numbers printed near points on graph.)

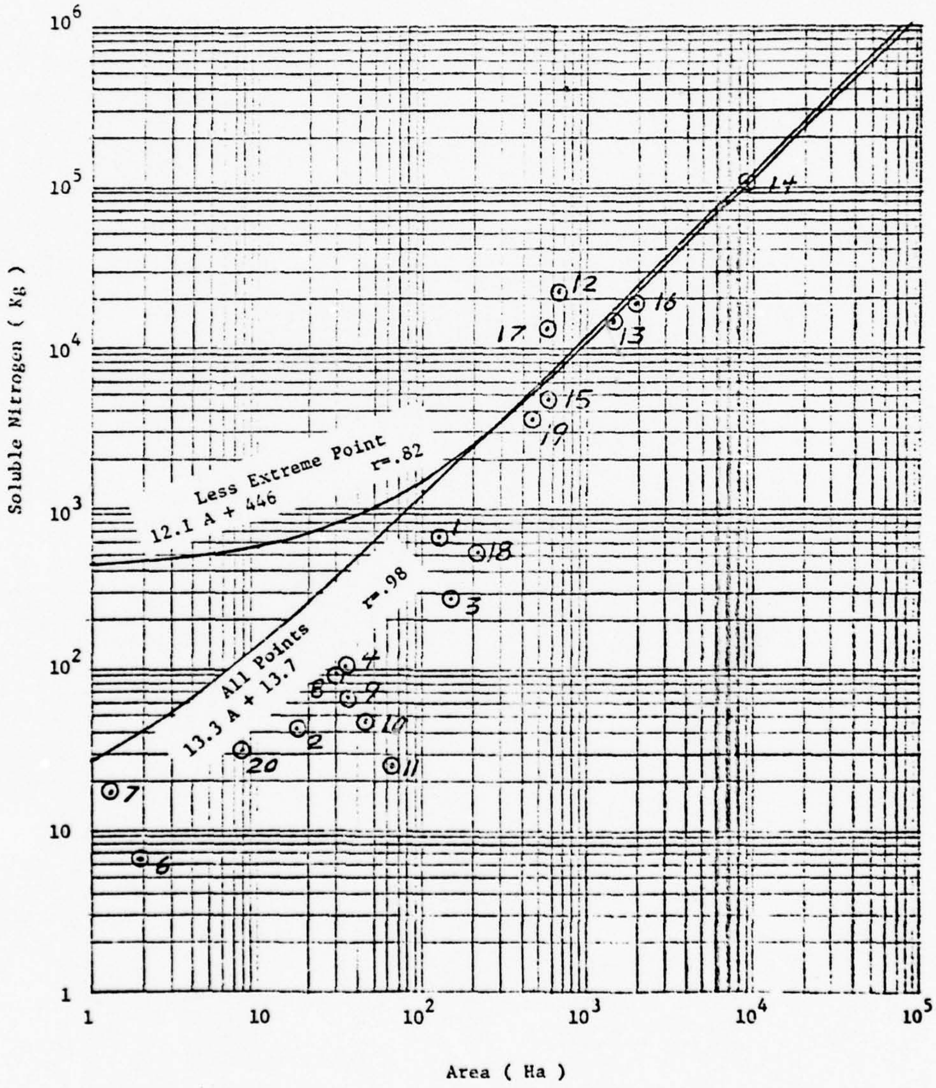


FIGURE 11 - MEASURED AVERAGE ANNUAL SOLUBLE PHOSPHORUS VS AREA with arithmetic linear regressions. (Watershed numbers printed near points on graph.)

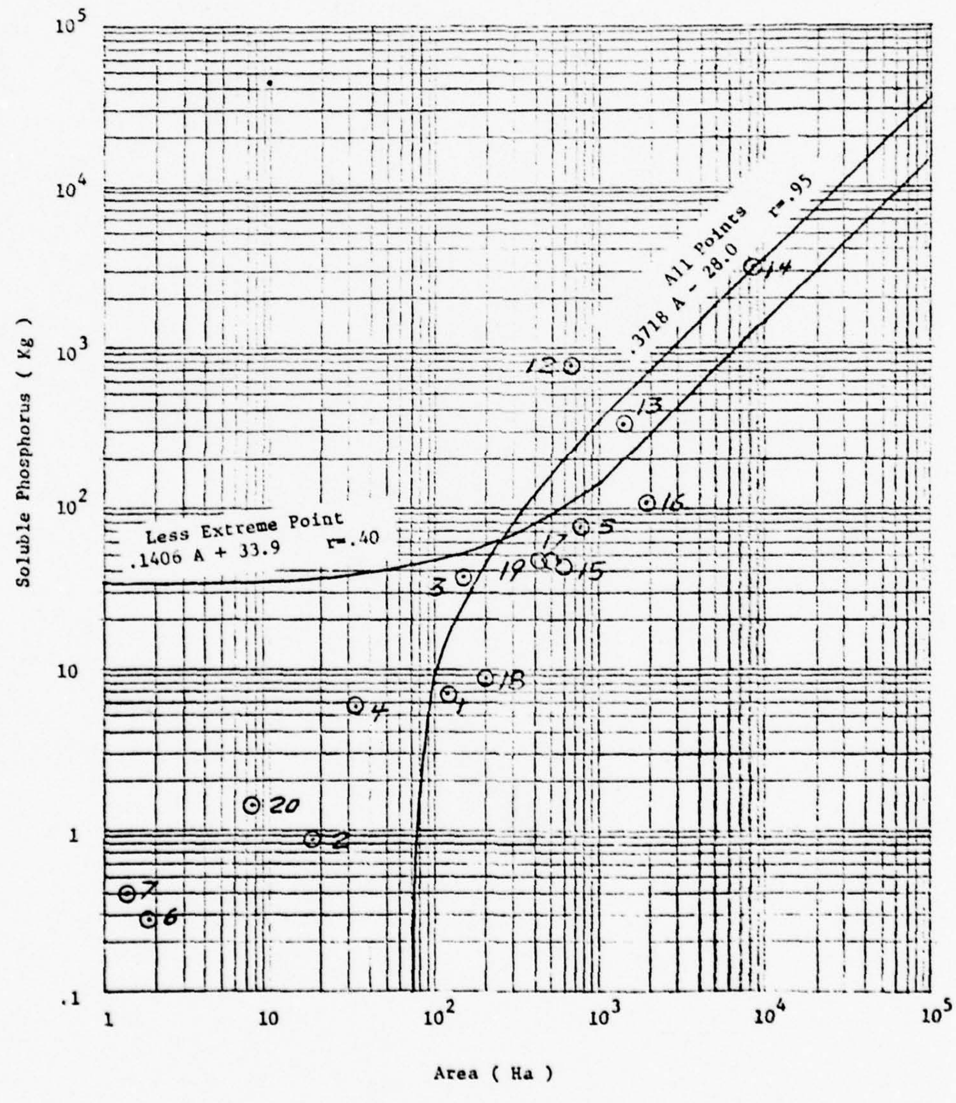


FIGURE 12 - MEASURED AVERAGE ANNUAL SOLUBLE NITROGEN VS AREA x SEDIMENT DELIVERY with arithmetic linear regressions.
(Watershed numbers printed near points on graph.)

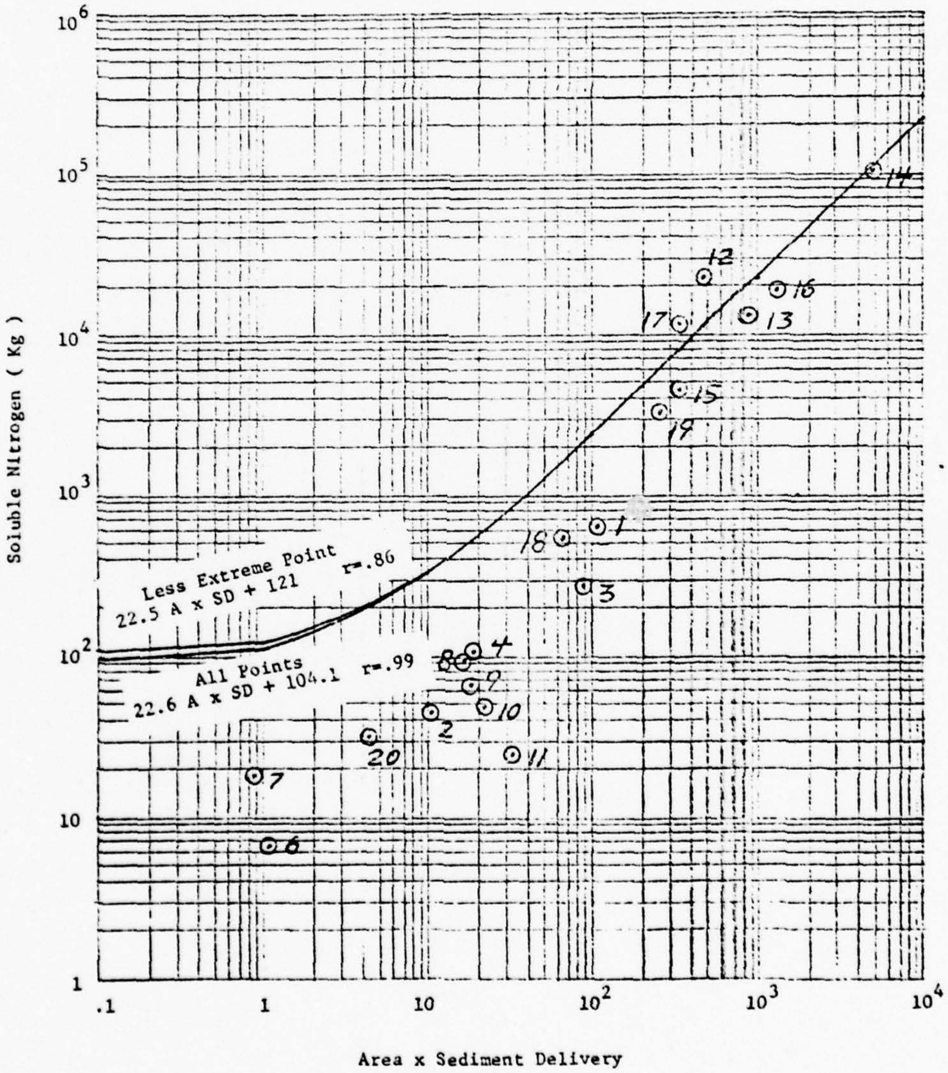


FIGURE 13 - MEASURED AVERAGE ANNUAL SOLUBLE PHOSPHORUS VS AREA x SEDIMENT DELIVERY with arithmetic linear regressions.
(Watershed numbers printed near points on graph.)

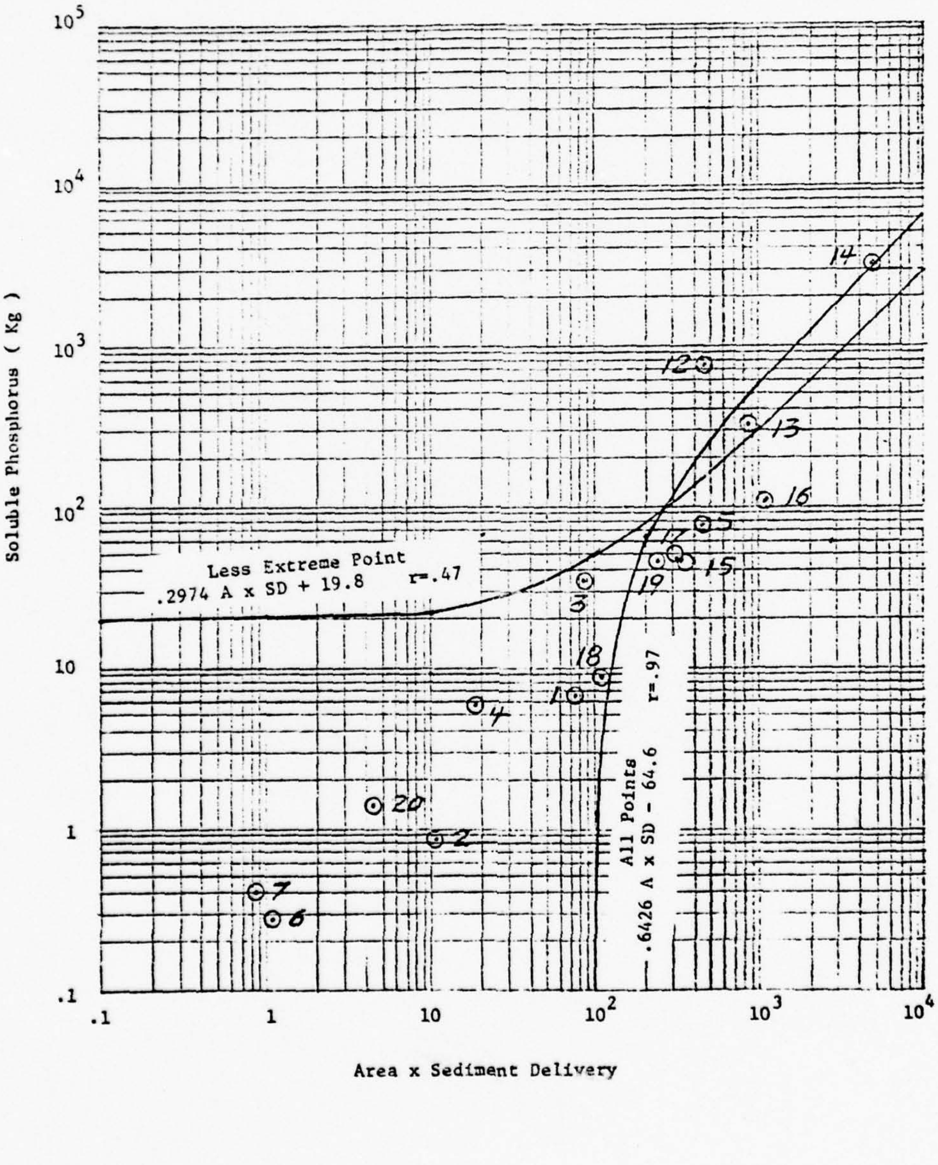


FIGURE 14 - MEASURED AVERAGE ANNUAL SOLUBLE NITROGEN PER HECTARE VS SEDIMENT DELIVERY with arithmetic linear regressions. (Watershed numbers printed near points on graph.)

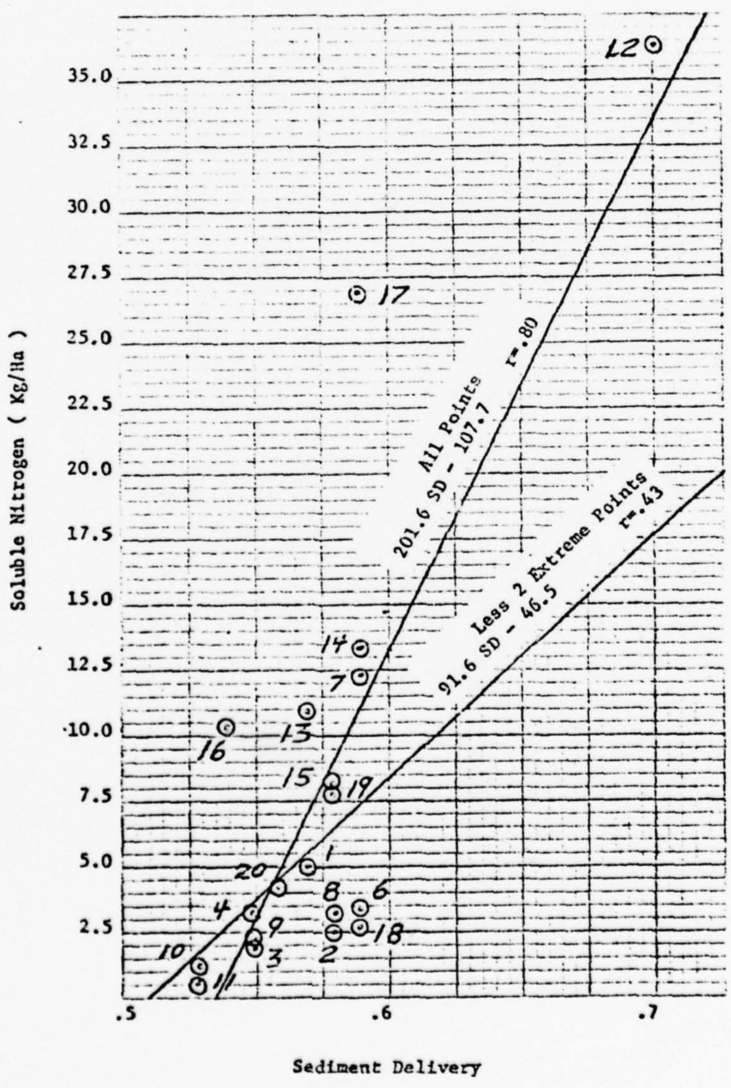
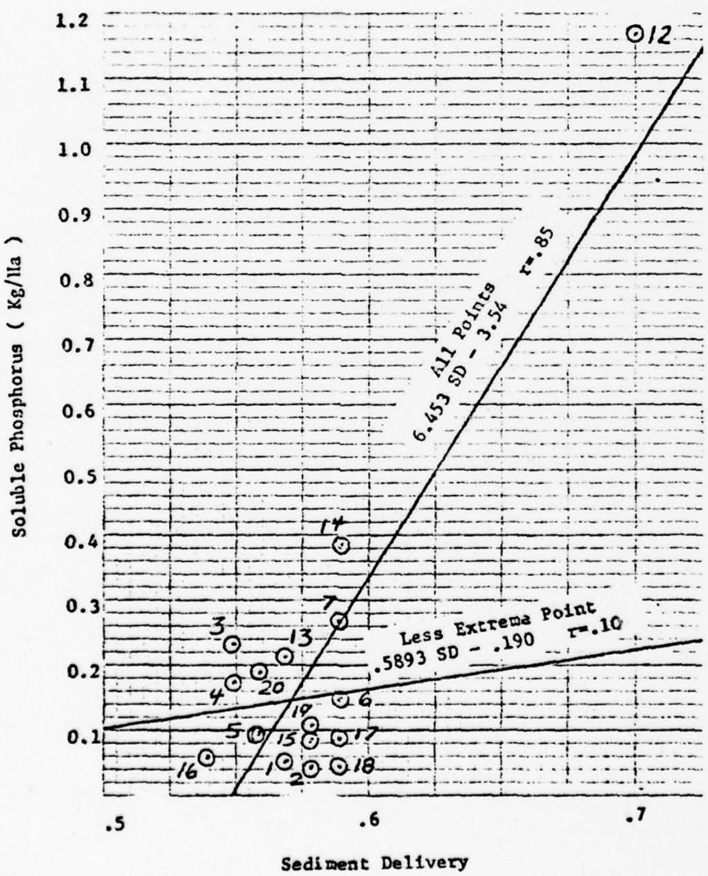


FIGURE 15 - MEASURED AVERAGE ANNUAL SOLUBLE PHOSPHORUS PER HECTARE VS SEDIMENT DELIVERY with arithmetic linear regressions. (Watershed numbers printed near points on graph.)



Figures 14 and 15. From these graphs it can be seen that high correlations are mostly the result of one extreme point where SD = 0.7. When this point is neglected correlations are greatly reduced and the regression lines change abruptly.

The reader may remember from the earlier discussion of the sediment delivery that most values were near .56 but that one was .70 as the result of different soil texture. This one value corresponds to the extreme point on these graphs and is almost entirely responsible for any correlation between sediment delivery and soluble nutrient load. The significance seems to be that soil texture may dominate the value of sediment delivery and correlate closely to soluble nutrient load. It is also possible, however, that this apparent dependence on soil texture is only an artifact of the one data point where texture and nutrient load happen to change and that no cause and effect relationship exists.

(3) Area x Drainage Density

The plot of the product of area times drainage density against soluble nutrient loads are on Figures 16 and 17. Here as with the sediment delivery graphs the nitrogen load seems to have a more evident relationship to the area times drainage density product. Again, however, exclusion of the extreme point markedly reduces the correlation with phosphorus load.

Plots of drainage density against nutrient loads per unit area

FIGURE 16 - MEASURED AVERAGE ANNUAL SOLUBLE NITROGEN VS AREA x DRAINAGE DENSITY with arithmetic linear regressions. (Watershed numbers printed near points on graph.)

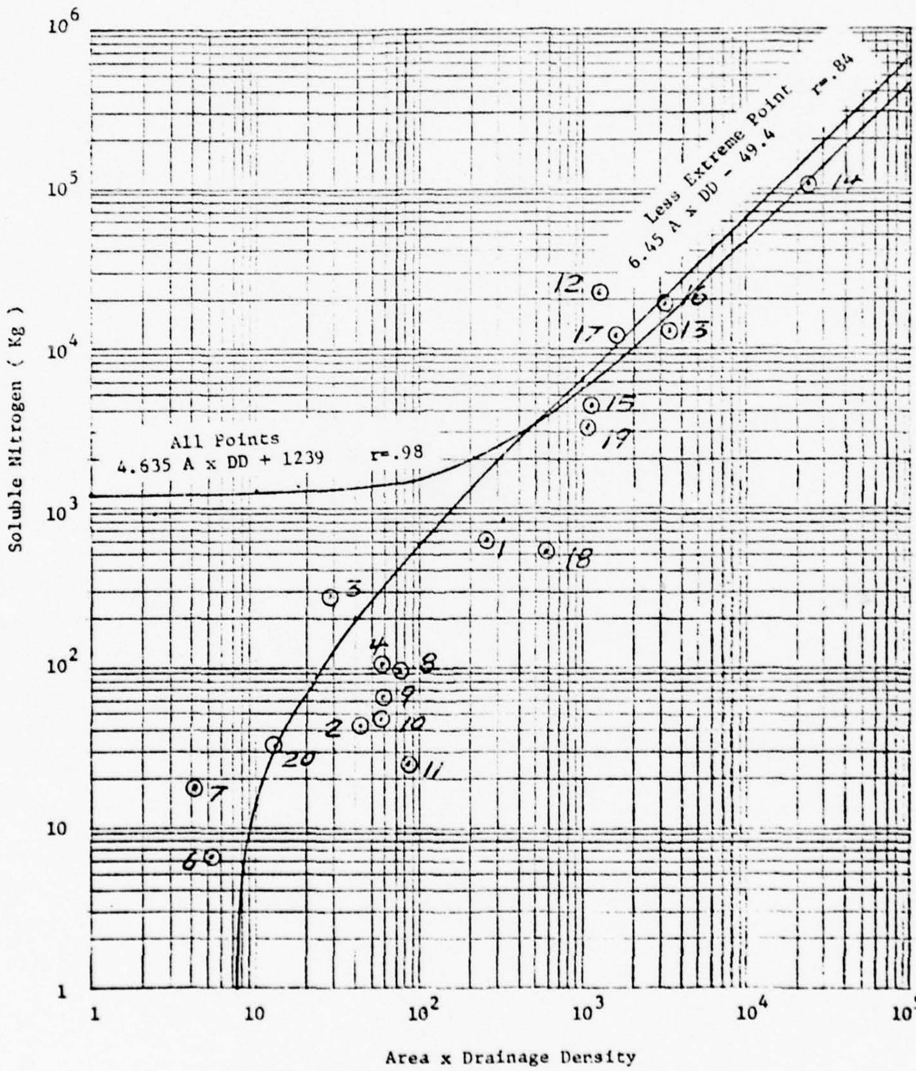


FIGURE 17 - MEASURED AVERAGE ANNUAL SOLUBLE PHOSPHORUS VS AREA x DRAINAGE DENSITY with arithmetic linear regressions. (Watershed numbers printed near points on graph.)

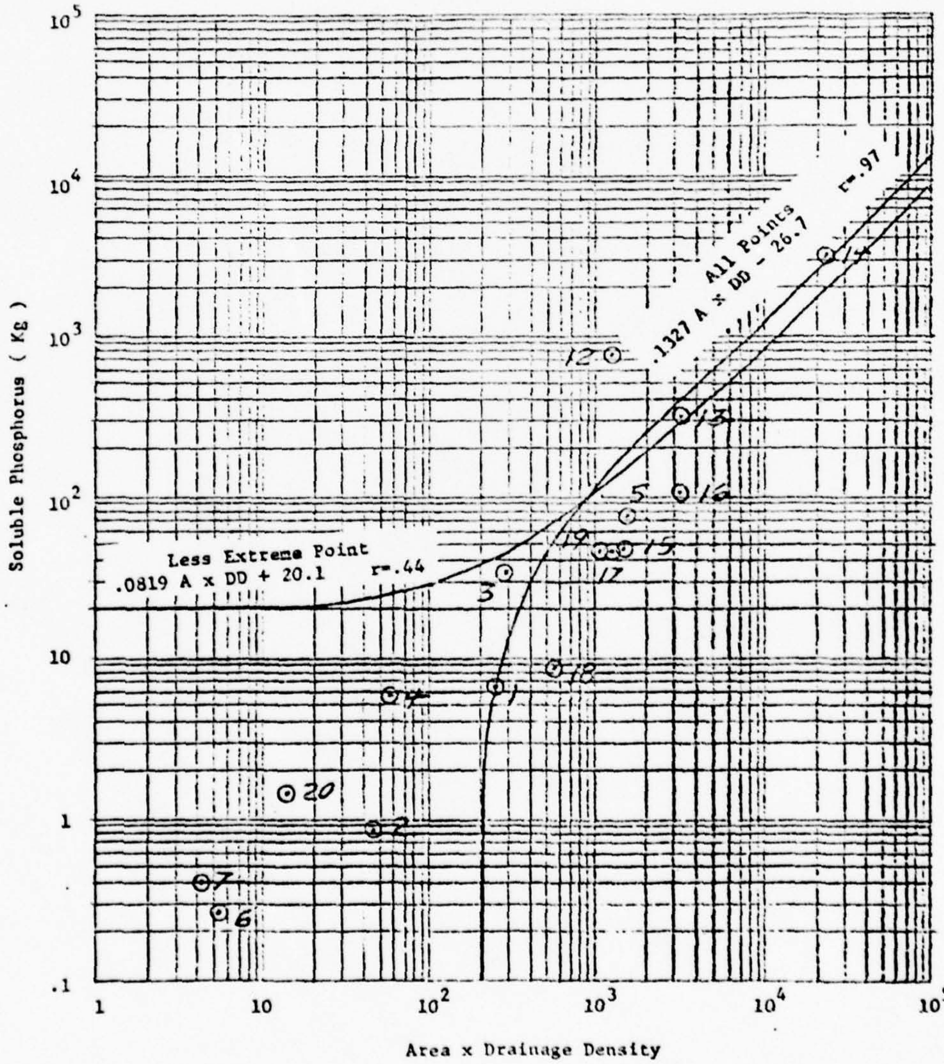


FIGURE 18 - MEASURED AVERAGE ANNUAL SOLUBLE NITROGEN PER HECTARE VS DRAINAGE DENSITY
with arithmetic linear regressions.
(Watershed numbers printed near points on graph.)

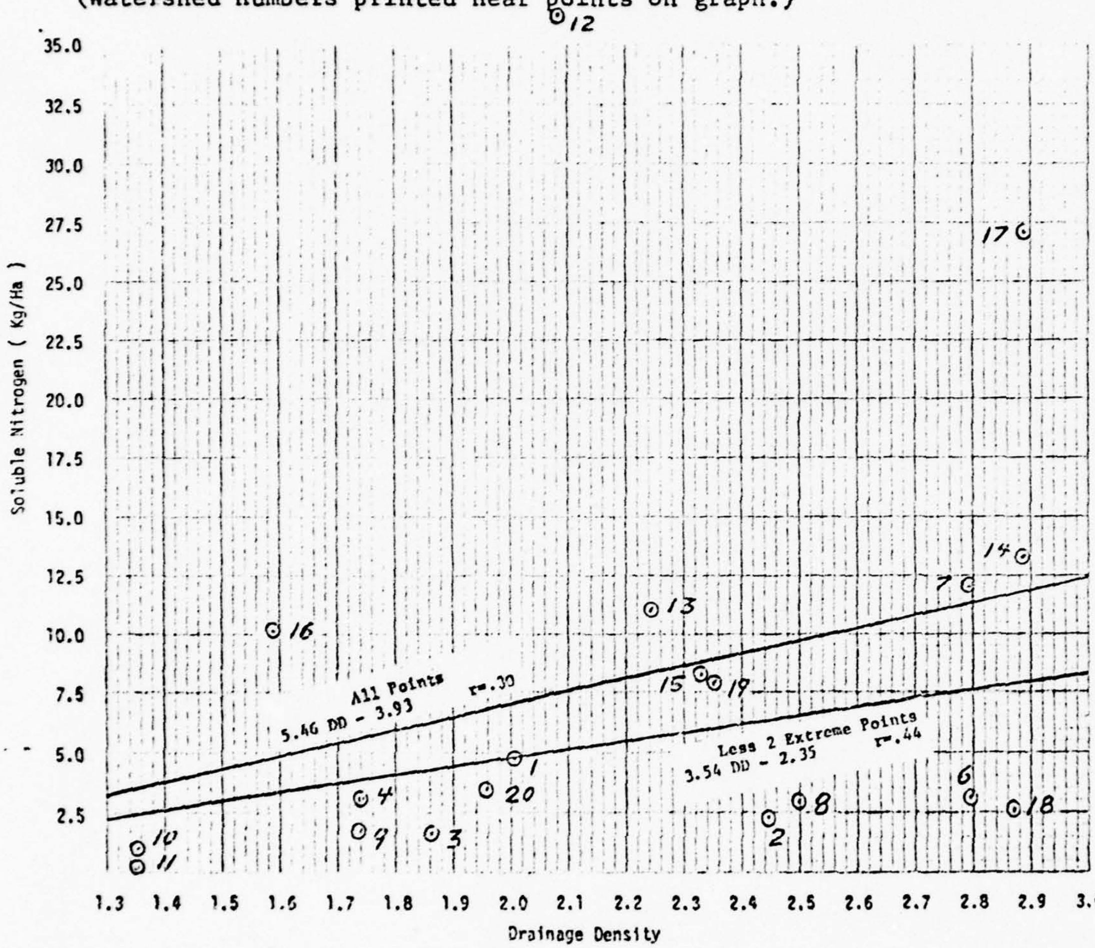
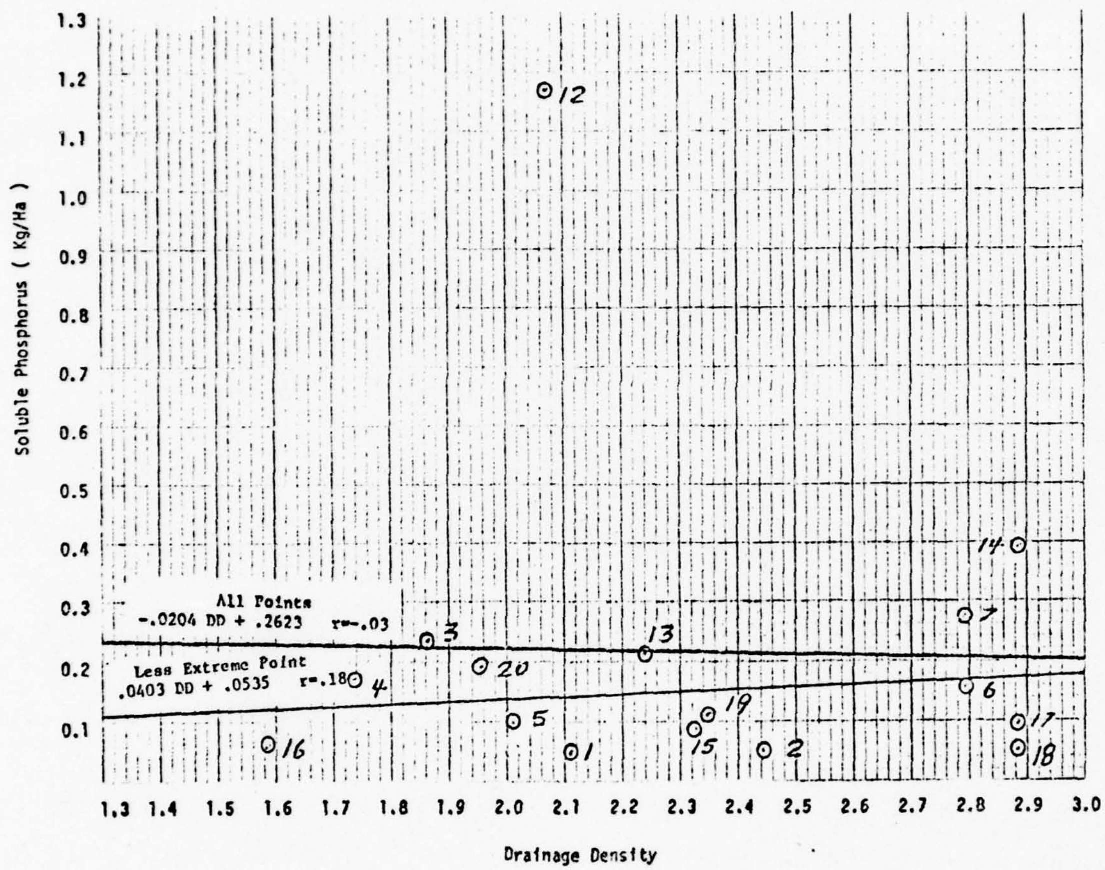


FIGURE 19 - MEASURED AVERAGE ANNUAL SOLUBLE PHOSPHORUS PER HECTARE VS DRAINAGE DENSITY
with arithmetic linear regressions.
(Watershed numbers printed near points on graph.)



(Figures 18 and 19) show very small correlations and the regression lines are almost horizontal which indicates that unit area loads seem to be independent of drainage density.

d. The importance of Area

The conclusion that I have drawn from the preceding analysis is that one term in the MRI model alone is related to the soluble nutrient load of a stream. This is the drainage area of the basin. All the other variables appear simply to add noise. There may be some relation of sediment delivery to load but it is related to soil texture rather than drainage density. The remainder of the study, then is concerned with the relation of basin area to soluble nutrient load and an attempt to devise some method for predicting loads from basin areas.

One point, however should be noted here. That is, the apparent distribution of the points on the preceding graphs along what may be seen as straight lines on log paper. Such lines, although not shown here, may be derived by taking linear regressions of the log of the dependent variable against the log of the independent variable. Such calculations have been made and the results shown in Table IX. These equations show very similar exponents within the two different nutrients and especially close values for the three equations involving either area alone or area multiplied by a second term such as

TABLE IX - SELECTED NITROGEN AND PHOSPHORUS LOGARITHMIC LINEAR REGRESSIONS AND CORRELATIONS

Nitrogen		Phosphorus	
$N_S = .01\ (N_{TP})^{1.14}$	r=.83	$P_S = .10\ (P_{TP})^{.71}$	r=.77
$N_S = 1.78\ (A)^{1.21}$	r=.94	$P_S = .51\ (A)^{.80}$	r=.88
$N_S = 3.14\ (A \times SD)^{1.23}$	r=.95	$P_S = .72\ (A \times SD)^{.82}$	r=.89
$N_S = .66\ (A \times DD)^{1.22}$	r=.96	$P_S = .25\ (.A \times DD)^{.81}$	r=.88

sediment delivery. The implication is that area dominates the relationships and supports that conclusion made earlier based on arithmetic rather than logarithmic plots and regressions. No attempt is made here to develop any relationship of area to nutrient load that involves exponential values. While such a relationship may exist, I cannot envision a set of processes that might produce it and would want much more data before suggesting such a dependency.

e. The Distribution of Soluble Nutrient Loads per Unit Area

The first step in my investigation of the distribution of soluble nutrient loads per unit area was to see if there was a connection between the loads of nitrogen and phosphorus. To do this I studied the ratio of nitrogen to phosphorus on the 15 watersheds for which both nutrients were reported. The unit loads of nitrogen and phosphorus and the ratios of these loads are shown on Figure 20. The value of the ratio of the nutrient loads varied from a low of 7.7 to a high of 301.7. There appeared to be no observable consistency to the ratio, therefore there was assumed to be no connection between unit area loads of the two nutrients studied.

The bar graphs of unit area loads of nitrogen and phosphorus shown on Figures 21 and 22 seem to show a common range of such values. The frequency distribution of the unit area loads are shown on Figures 23 and 24. On these graphs an X indicates one occurrence of

FIGURE 20 - SOLUBLE NITROGEN & PHOSPHORUS LOADS & THEIR RATIOS

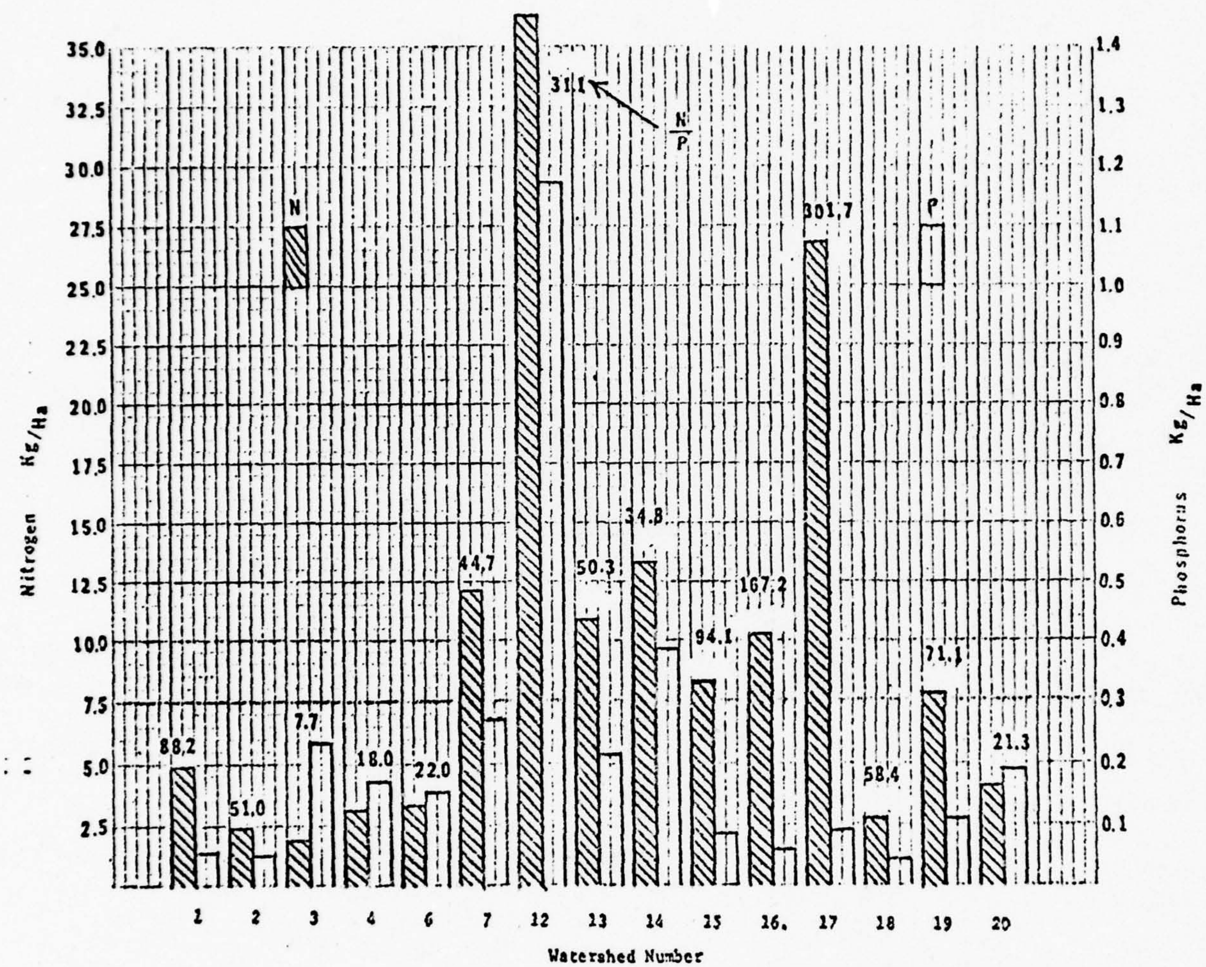


FIGURE 21 - SOLUBLE NITROGEN LOADS

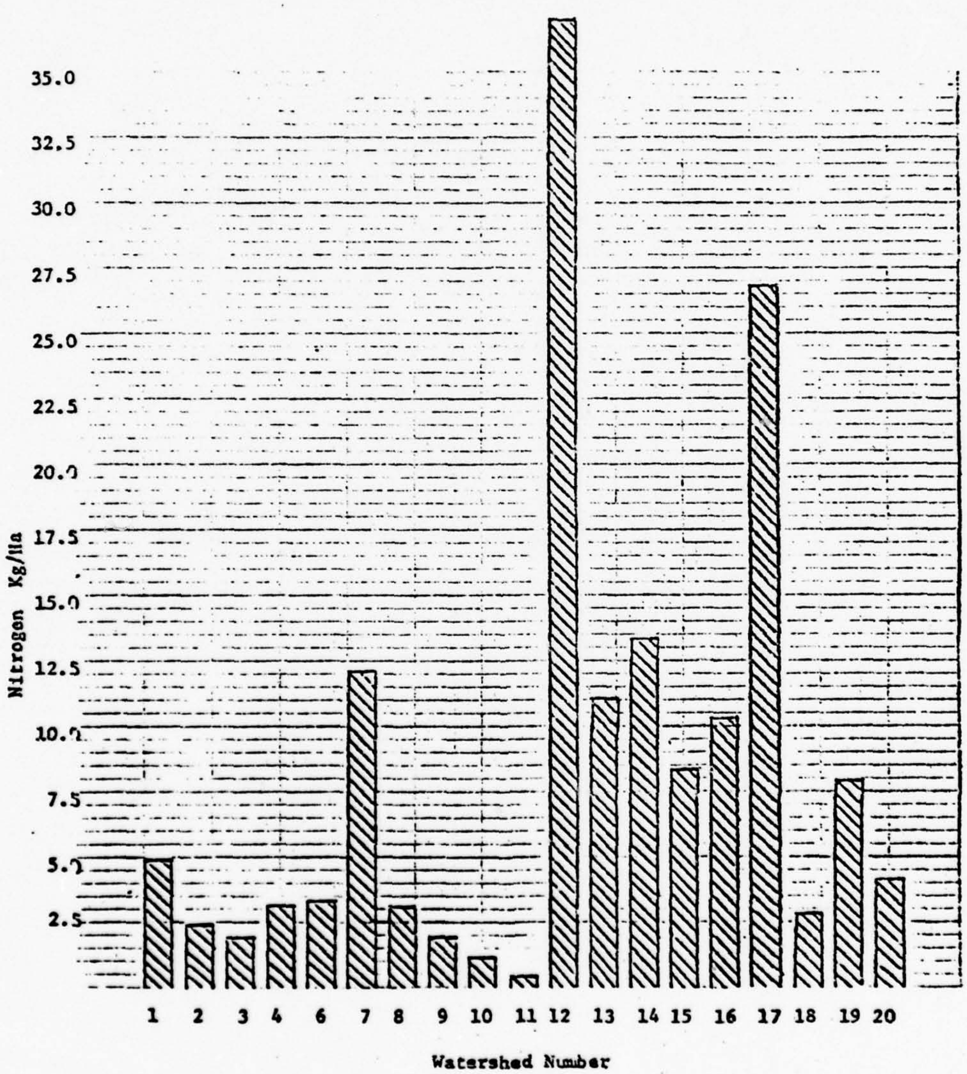


FIGURE 22 - SOLUBLE PHOSPHORUS LOADS

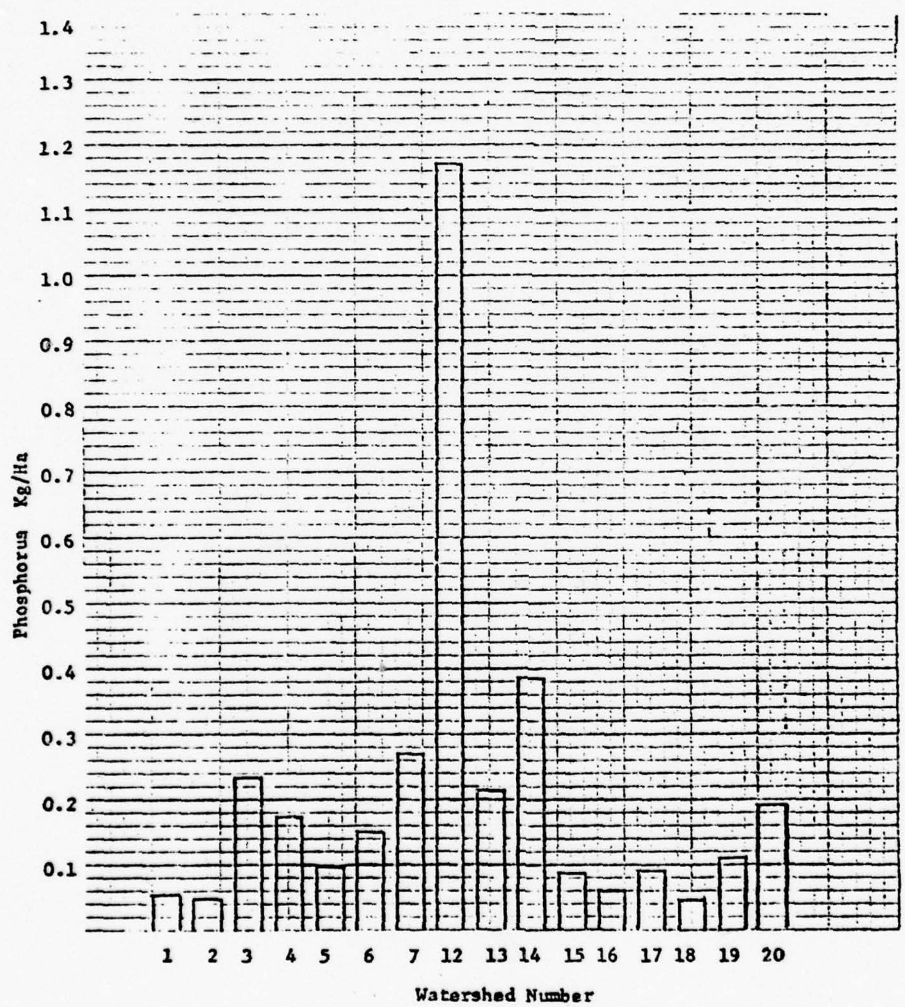


FIGURE 23 - DISTRIBUTION OF SOLUBLE NITROGEN LOADS

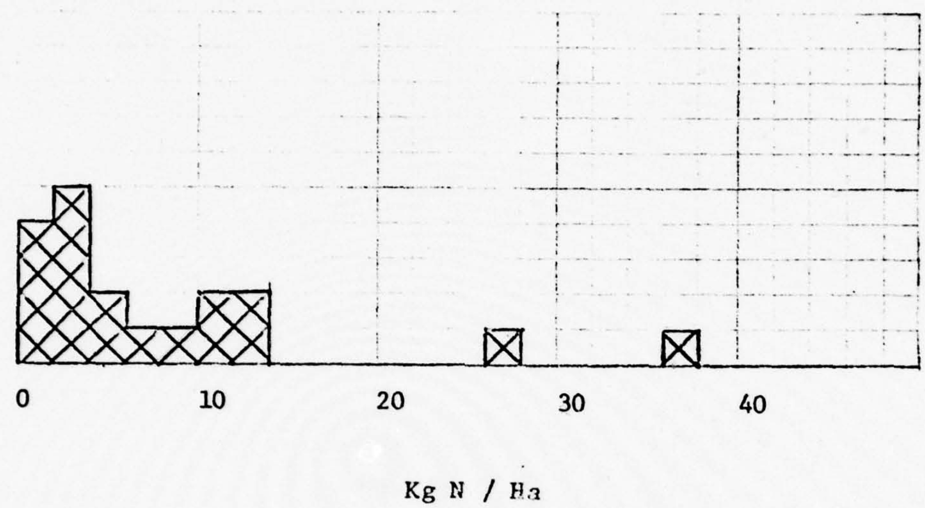
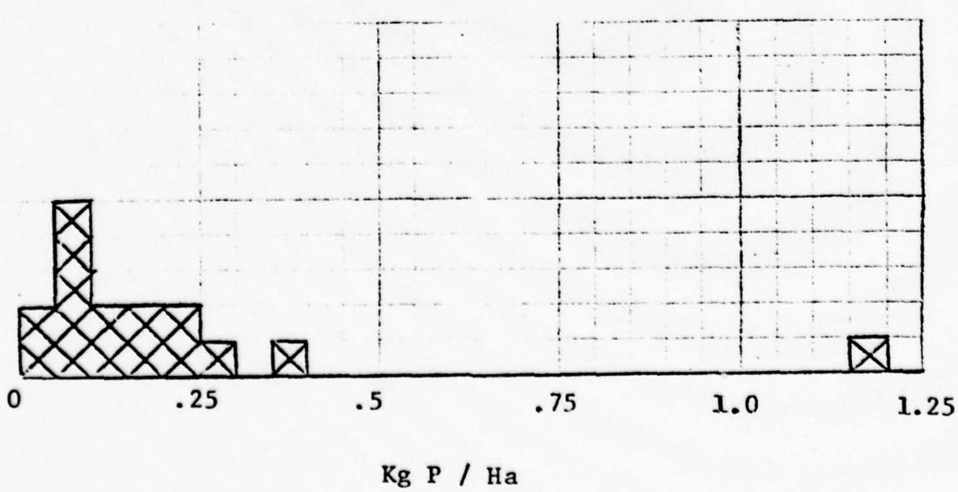


FIGURE 24 - DISTRIBUTION OF SOLUBLE PHOSPHORUS LOADS



a load within the range shown. Both of these distributions show a sharp increase to a peak near the origin and a less sharp decline tailing down to very few points at higher ranges of unit area load.

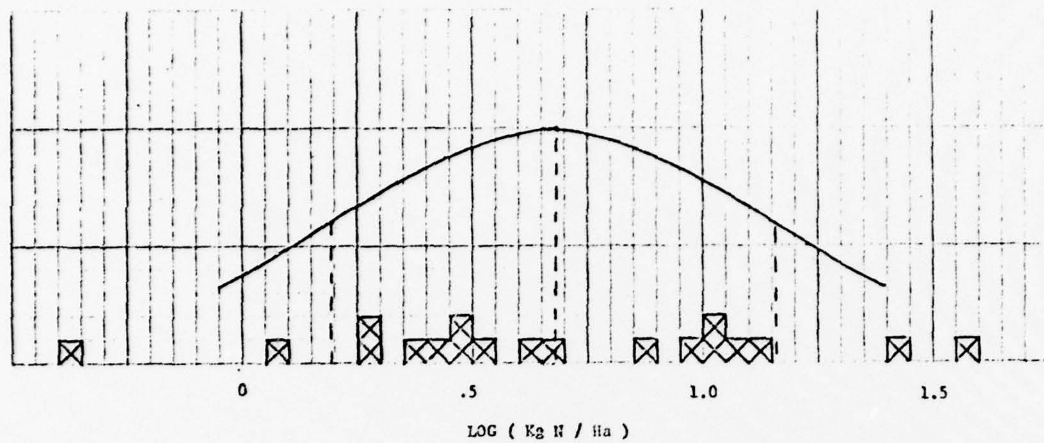
Such a distribution is characteristic of a set of values the logarithms of which are normally distributed. Based on this observation I assumed the distribution of the logarithms to be normal and calculated the means and standard deviations. From these the distribution curves shown in Figures 25 and 26 were made. The top portion (Figures 25a and 26a) show the normal curve on the logarithmic axis with the actual occurrences of load logarithms indicated. The reader may judge for himself if this is, in fact, a normal distribution. The observation that the mean logarithm corresponds to the median load supports this conclusion, however. Admittedly, more data would be helpful. The lower curve is the same distribution on an arithmetic scale for reference only.

Figures 27 and 28 are the soluble nutrient load versus area plots of points, but with lines drawn representing the mean and plus and minus one standard deviation of the log of load per unit area times the area. As can be seen these lines bound a rather well defined range of values that could be used to estimate expected nutrient load for any given watershed for which the area is known.

To the degree that the statistics of this rather limited sample represent the distribution of nutrient loads in all streams they can

FIGURE 25 - DISTRIBUTION OF LOGARITHMS OF SOLUBLE NITROGEN LOADS

25a



25b

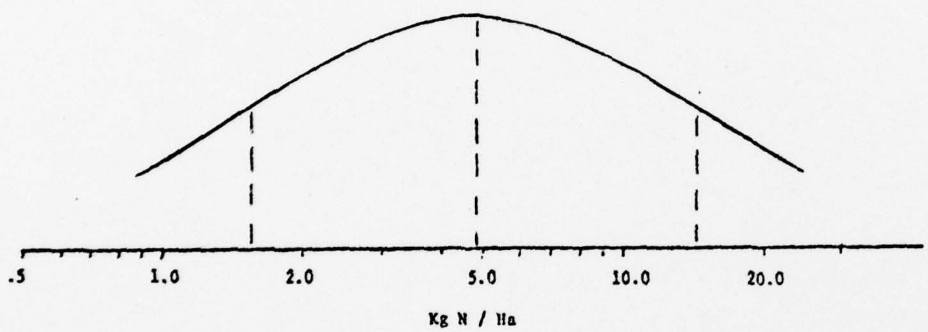


FIGURE 26 - DISTRIBUTION OF LOGARITHMS OF SOLUBLE PHOSPHORUS LOADS

26a

26b

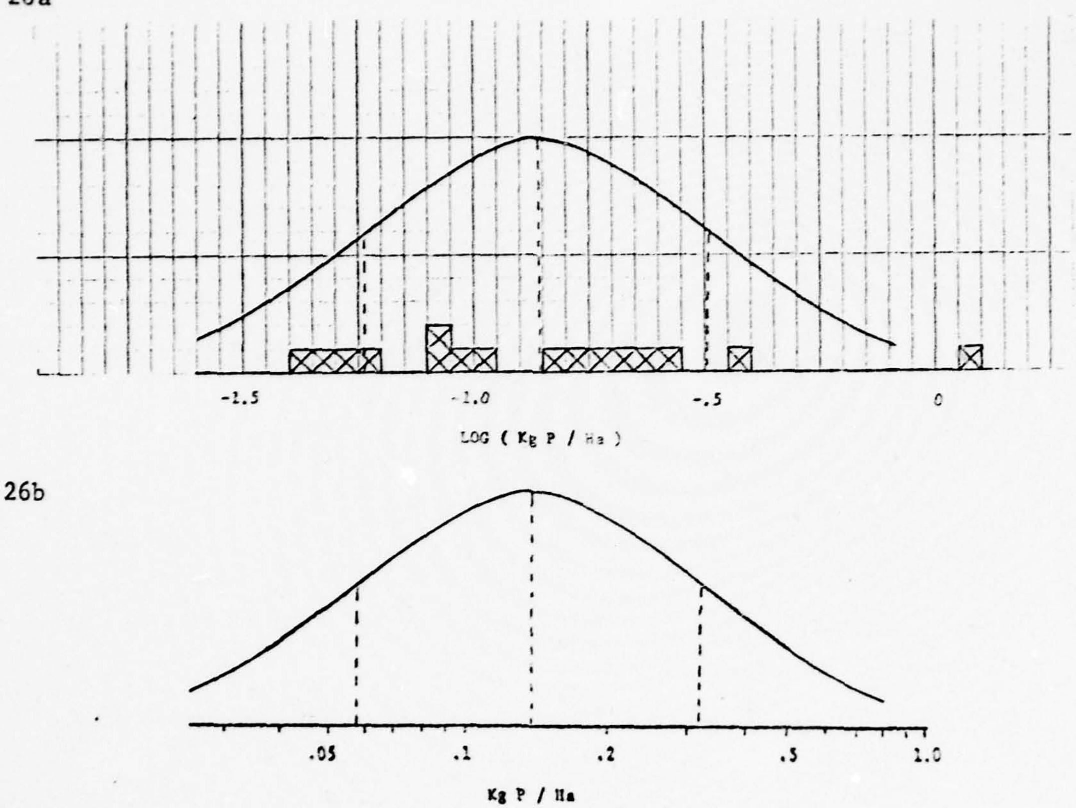


FIGURE 27 - MEASURED AVERAGE ANNUAL SOLUBLE NITROGEN VS AREA with mean and ± 1 standard deviation of the logs of the loads.
(Watershed numbers printed near points on graph.)

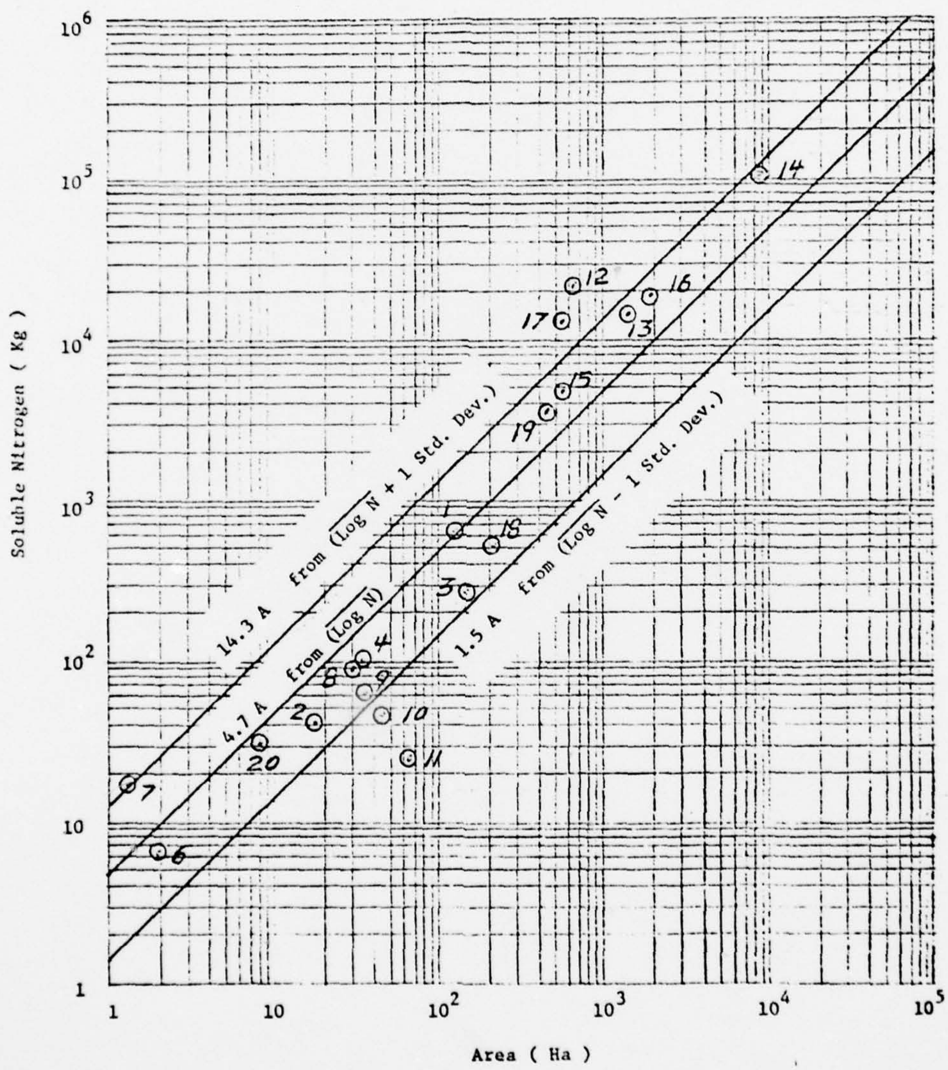
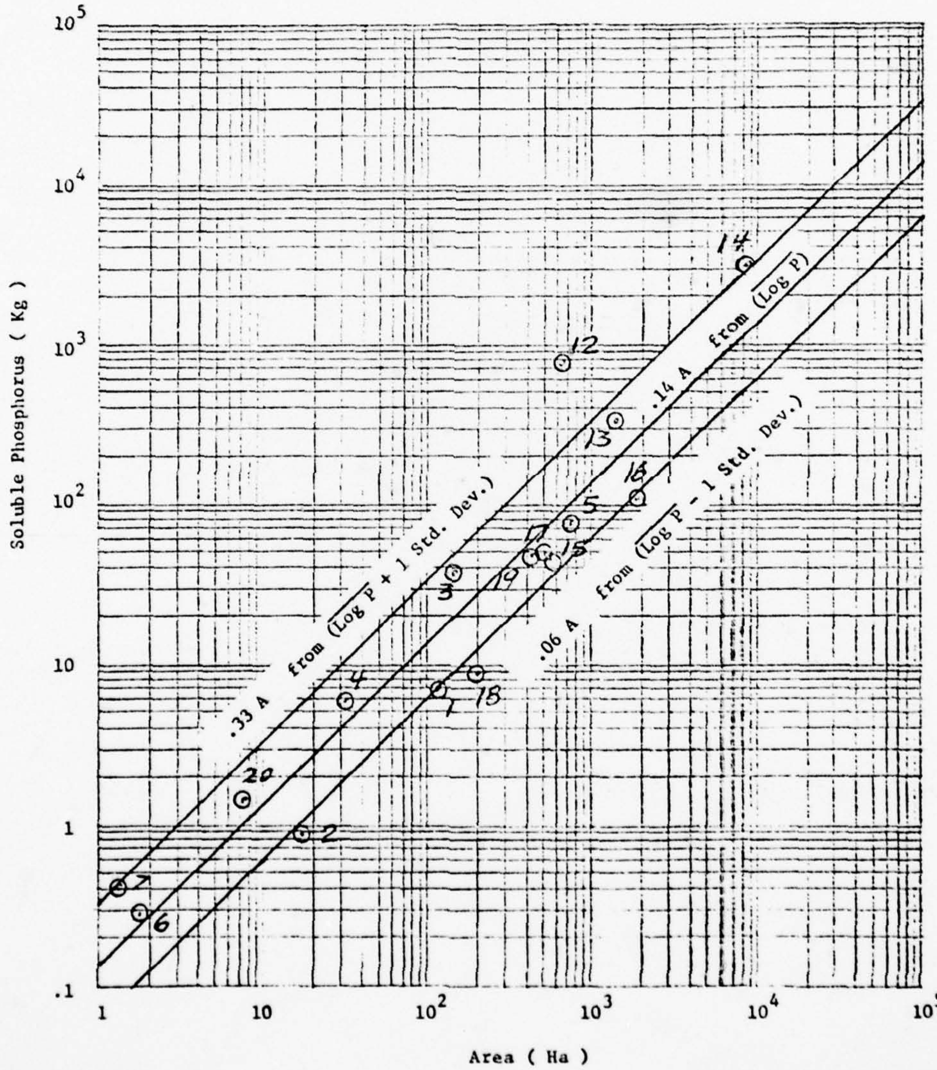


FIGURE 28 - MEASURED AVERAGE ANNUAL SOLUBLE PHOSPHORUS VS AREA with mean and ± 1 standard deviation of the logs of the loads.
(Watershed numbers printed near points on graph.)



be used to calculate the probability that actual load per unit area of any stream will not exceed a given value. Such probabilities and associated unit loading rates have been calculated and are shown in Table X. Lines representing these loads and probabilities are also plotted on area and nutrient load graphs (Figures 29 and 30).

The net result is that if these normal distributions of logarithms are indeed real the planner may choose a value of nutrient load and find the probability that the actual value will not exceed it or conversely choose a probability and find the load that will give him that degree of assurance of not being exceeded. For example, if the planner wants to be 90 percent sure that the non-point pollution of nutrients he predicts will not be exceeded he would predict 19.5 Kg/Ha of nitrogen and .42 Kg/Ha of phosphorus. If average values are desired he would use the .50 probability value.

TABLE X - PROBABILITIES AND LOADING RATES

Probability of not exceeding stated loading rate	Loading Rate	
	Kg N/Ha	Kg P/Ha
.1	1.2	.05
.2	1.9	.07
.3	2.7	.09
.4	3.6	.11
.5	4.7	.14
.6	6.3	.17
.7	8.4	.21
.8	12.0	.29
.9	19.5	.42
.95	29.0	.57

FIGURE 29 - SOLUBLE NITROGEN VS AREA WITH PROBABILITIES

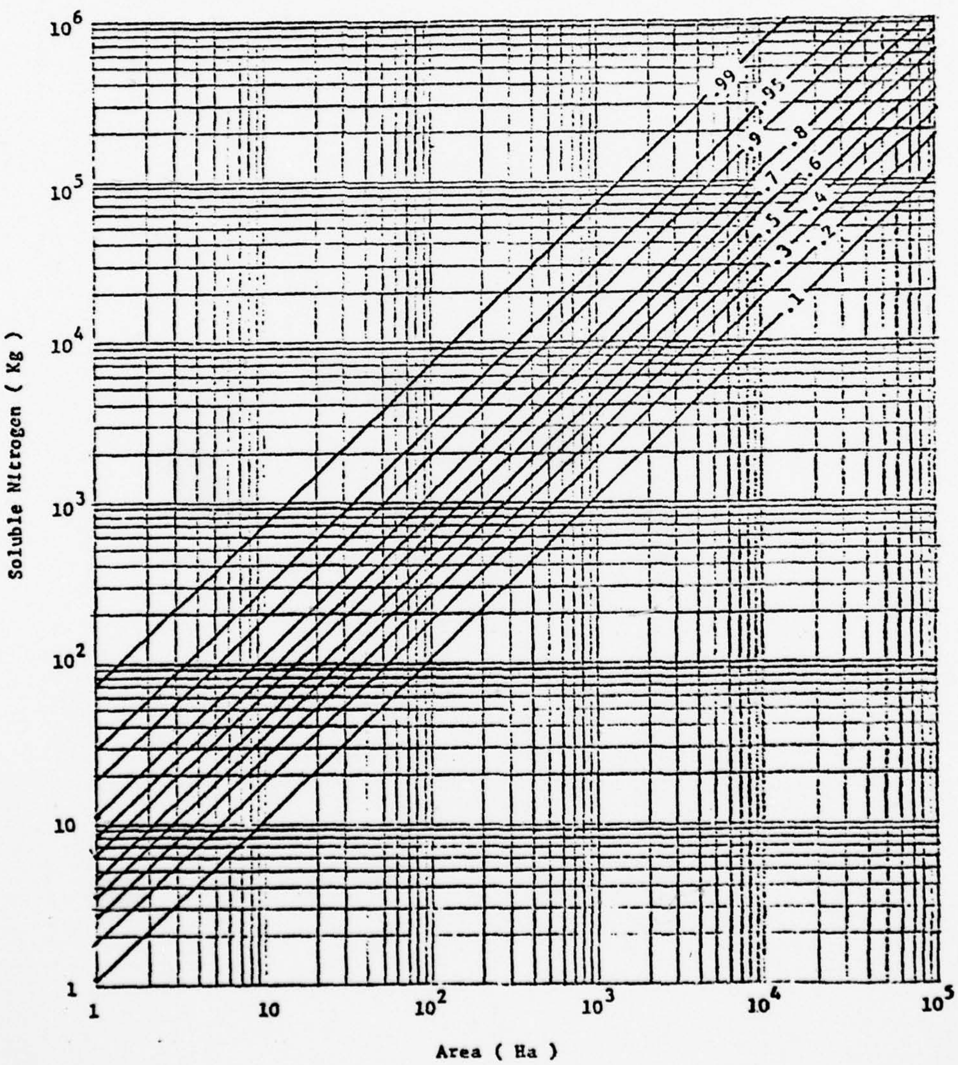
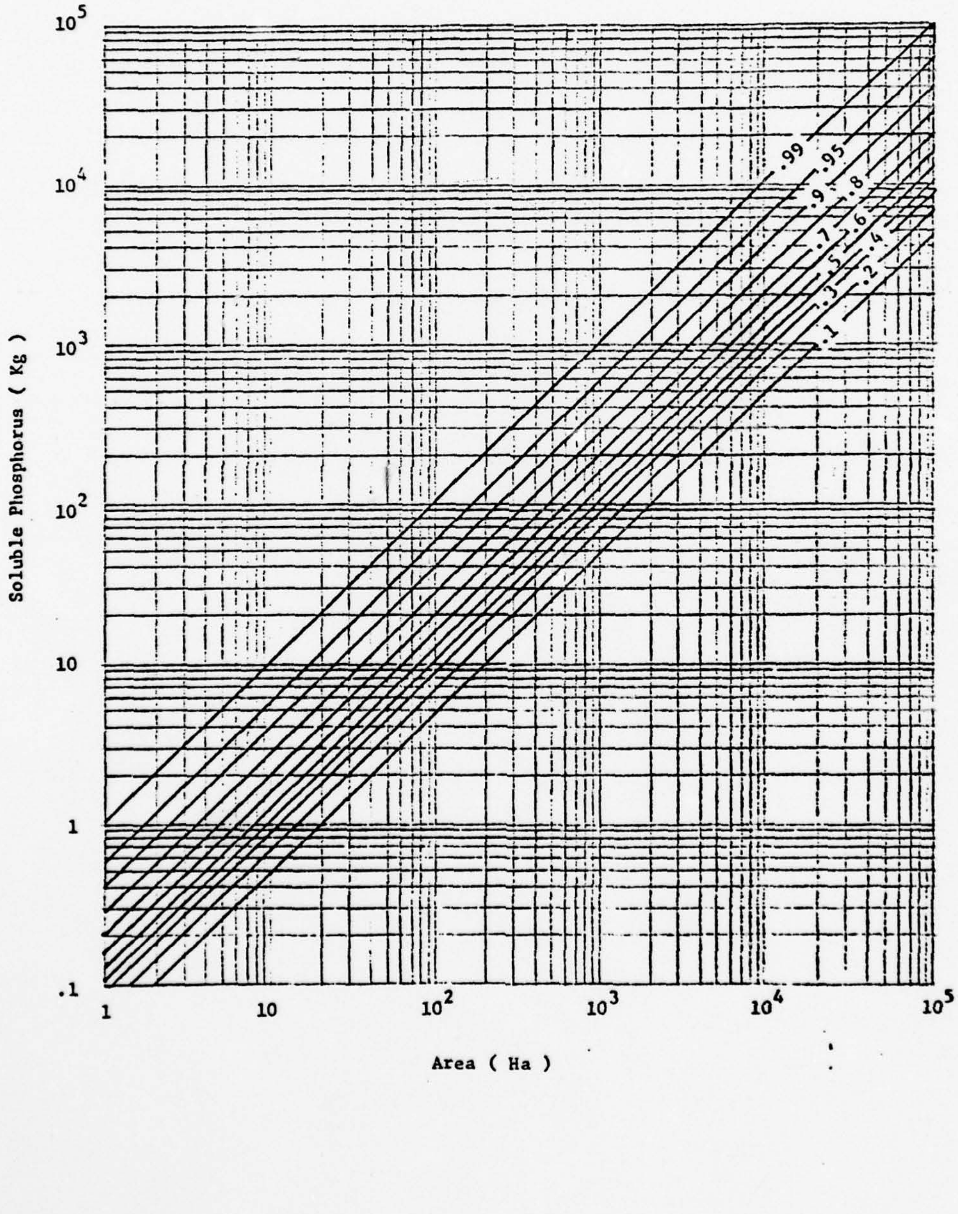


FIGURE 30 - SOLUBLE PHOSPHORUS VS AREA WITH PROBABILITIES



V. DISCUSSION AND CONCLUSIONS

A. Universal Soil Loss Equation

There is too little data in this study for any hard conclusions to be drawn regarding the accuracy of the soil loss equation. There does seem to be a pattern of sediment load values that are generally one-tenth of that predicted by the equation however, with a smaller number of values very close to predictions. More data are needed to give a true test of the value of the soil loss equation for the prediction of sediment loads for watersheds.

B. Total Nutrient Load Prediction

While data is limited, the MRI model generally over-predicts the total nutrient load of nitrogen by a factor of 10 and phosphorus by a factor of from 40 to 60. It is possible that the error in the nitrogen prediction is a result of over-prediction of annual sediment load by the Universal Soil Loss Equation since the magnitude of the difference between actual and predicted values are the same for both. Again these conclusions are limited. Confirmation requires more data than are reported here.

C. Ratio of Nitrate to Total Nitrogen in Solution

The ratio of nitrate nitrogen to total nitrogen in solution was

almost constant for all streams for which I was able to obtain data. This leads to the conclusion that, in general, this ratio is constant and of total nitrogen in solution a fixed fraction can be expected to be in the oxidized form (nitrate) and a fixed fraction will also be in the reduced form (mostly ammonia). The fraction of nitrate is generally .56 while .44 of the nitrogen is in reduced forms. This conclusion is reinforced by the fact that linear regressions of soluble nitrate nitrogen against area and against predicted total nitrogen (Table VII) had just over one-half the slope of similar regressions of total soluble nitrogen against these same two independent variables. The correlations of nitrate plots were for all practical purposes identical to those of total soluble nitrogen all of which would be expected if the fraction of nitrate were constant.

D. The MRI as a Soluble Nutrient Model

The MRI model was found to over-predict both soluble nitrogen and phosphorus loads in the streams studied here. There was a high correlation of predicted load to actual load but upon analysis this was determined to be almost entirely due to the area term in the model. Thus the model does not appear to predict soluble nutrient load and most of the terms in the model are little more than random variables having no impact on prediction success. With the exception of drainage area, the only term that may be useful to study

further is sediment delivery ratio and then only as soil texture affects it.

E. Nutrient Loads on a Per Area Basis

From this study it appears that the logarithms of the soluble nutrient loads per unit area are normally distributed. There are probably some factors, sets of factors, or processes that determine where in the distribution the loads for any one stream will fall, but these controlling factors are not evident in this study. Not knowing the factors that influence load values, the best we can presently do is to describe the distribution of values and calculate the probability of not exceeding, or falling below, any given value of the soluble nutrient load.

This is an area where further study and work may produce very useful results. More data should be gathered to determine with more certainty if the distribution of unit area loads are as described here and the statistics then recalculated based upon the largest sample possible.

FOOTNOTES

[1] A. R. Robinson, "Sediment" in "A Primer on Agricultural Pollution", *Journal of Soil and Water Conservation,* March-April, 1971, p.61.

[2] C. S. Hunt, "Estimation of Water Pollution from Farming Activities", *Relationship of Agriculture to Soil and Water Pollution,* Cornell University Conference on Agricultural Waste Management, 1970, p. 242.

[3] Midwest Research Institute, *Cost and Effectiveness of Control of Pollution from Selected Nonpoint Sources,* Draft Final Report, July, 1975, 354 pages.

[4] *Ibid*

[5] W. H. Wischmeier and D. D. Smith, "Predicting Rainfall Erosion Losses from Cropland East of the Rocky Mountains", *Agriculture Handbook, 282,* U. S. Department of Agriculture, Agriculture Research Service, May, 1965.

[6] Midwest Research Institute, pp. 35, 36.

[7] Wischmeier and Smith, pp. 6, 7.

[8] *Ibid,* p. 5.

[9] Soil Conservation Service, *Soil Series of the United States, Puerto Rico and the Virgin Islands: Their Taxonomic Classification,* U. S. Department of Agriculture, 1972.

FOOTNOTES (Continued)

[10] Wischmeier and Smith, p. 8.

[11] *Ibid,* p. 9.

[12] Midwest Research Institute, p. 42.

[13] *Ibid,* p. 44.

[14] See 9 above.

[15] Midwest Research Institute, p. 47.

[16] *Ibid,* p. 50.

[17] *Ibid,* p. 48.

[18] H. Jenny, "A Study of the Influence of Climate Upon the Nitrogen and Organic Matter Content of Soil", Missouri Agricultural Experiment Station Research Bulletin, No. 152, 1930.

[19] Midwest Research Institute, p. 51.

[20] C. A. Parker, J. Adams, K. Clark, K. Jacob, and A. Mehring, "Fertilizer and Lime in the United States", *Miscellaneous Publication 586*, U. S. Department of Agriculture, 1946.

[21] *Ibid,* p. 27.

[22] *Ibid,* p. 26.

[23] See 8 above.

FOOTNOTES (Continued)

[24] R. Blong and N. Ryde, "Hillslope Morphometry and Classification: A New Zealand Example", *Z. Geomorph. N.F.*, Volume 19, No. 4, Dec. 1975, p. 410.

[25] Midwest Research Institute, *Water Pollution Abatement Technology Capabilities and Costs, Control of Watter Pollution from Selected Nonpoint Sources*, for the National Commission on Water Quality, Nov., 1975, p. 32.

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* Indicates article from which data was taken for one or more basins used in this study.

VITA

John E. Hesson was born on April 23, 1947, in Baltimore and was educated in the Baltimore County Public School System. He received a B. S. degree at the United States Military Academy at West Point in June of 1969 and has since been on active duty in the U. S. Army Corps of Engineers in Alaska, Vietnam, Virginia and Georgia. He is receiving graduate training at The Johns Hopkins University in preparation for an assignment as instructor in the Department of Earth, Space and Graphic Sciences at the Military Academy.